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U.S. ENVIRONMENTAL PROTECTION AGENCY

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CARBONACEOUS AND NITROGENOUS DEMAND STUDIES OF THE POTOMAC ESTUARY

(Summer 1977)

Annapolis Field Office, Region III
Environmental Protection Agency

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DISCLAIMER

The mention of trade names or commercial products in this report is for illustration purposes and does not constitute endorsement or recommendation by the U.S. Environmental Protection Agency.

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I. Introduction

During the summer of 1977 an intensive survey of the middle reach of the Potomac River (Figure #1) was undertaken by the A.F.O. All samples were collected under slack tide conditions. As part of this work, 20-day B.O.D. analyses were performed on selected stations (Table #1) to help define the major oxygen demand inputs and establish their effect upon the river. The fraction of the B.O.D. associated with nitrogenous oxygen demand was determined using an inhibitor to nitrification. To afford a more meaningful intrepretation of the results, a discussion is included on the B.O.D. test; nitrification; and the nature and action of the inhibitor employed.

Figure 1. Study Area

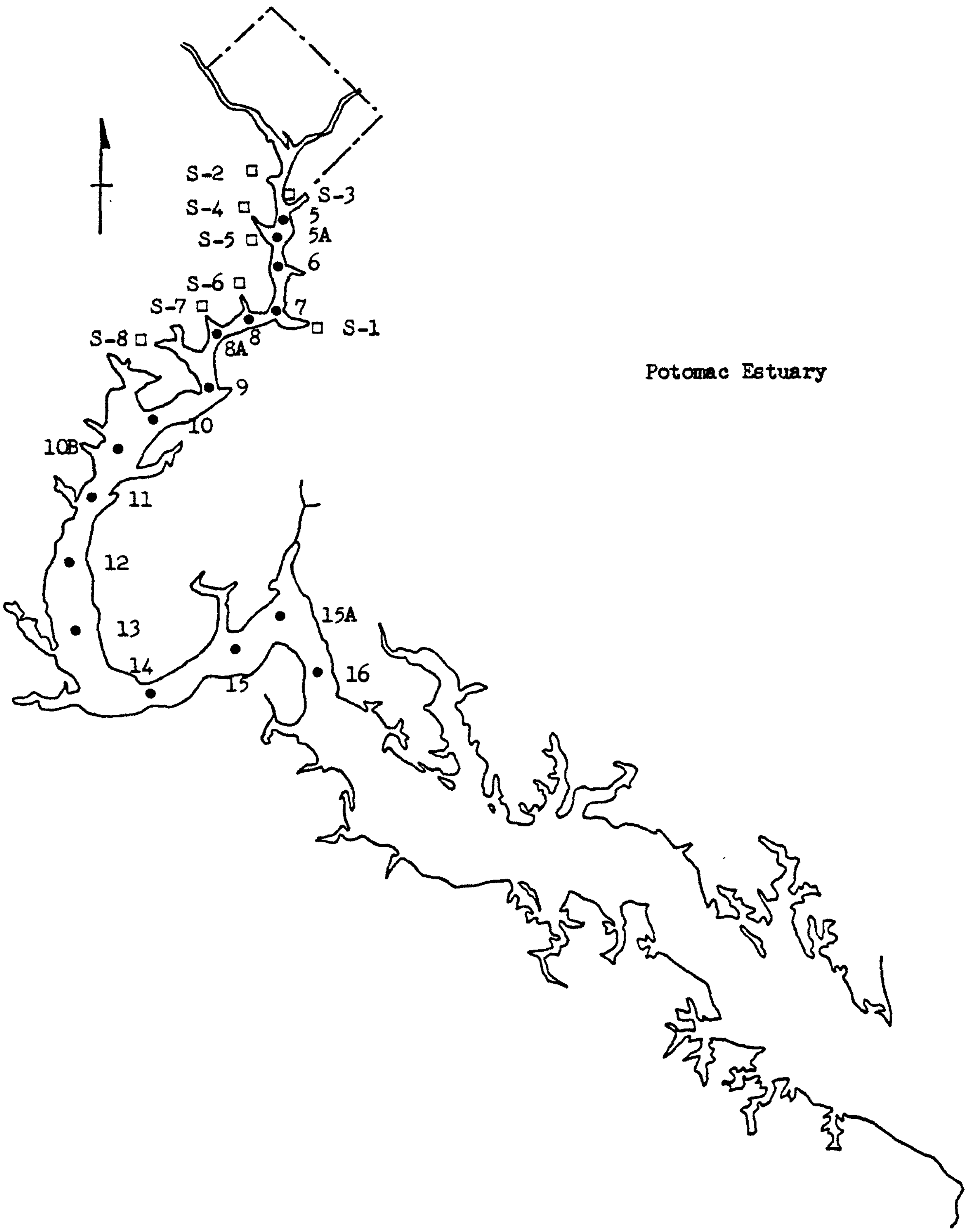


Table #1

Station Number	Stations for Long Term BOD/NOD	Station Name	RMI	Buoy Reference
P-8	X	Chain Bridge	0.0	
P-4		Windy Run	1.9	
1	X	Key Bridge	3.4	
1-A		Memorial Bridge	4.9	
2		14th Street Bridge	5.9	
3	X	Hains Point	7.6	C "1"
4	X	Bellevue	10.0	FLR-23' Bell
5	X	Woodrow Wilson Bridge	12.1	
5-A		Rosier Bluff	13.6	C "87"
6	X	Broad Creek	15.2	N "86"
7	X	Ft. Washington	18.4	FL "77"
8		Dogue Creek	22.3	FL "67"
8-A	X	Gunston Cove	24.3	R "64"
9		Chapman Point	26.9	FL "59"
10	X	Indian Head	30.6	N "54"
10-B		Deep Point	34.0	
11	X	Possum Point	38.0	R "44"
12		Sandy Point	42.5	N "40"
13		Smith Point	45.8	N "30"
14		Maryland Point	52.4	G "21"
15		Nanjemoy Creek	58.6	N "10"
15-A		Mathias Point	62.8	C "3"
16		Rt. 301 Bridge	67.4	

Station Number	Stations for Long Term BOD/NOD	Treatment Plant Name	∿ RMI*
S-1	X	Piscataway STP	18.4
S-2	X	Arlington STP	5.9
S-3	X	Blue Plains STP	11.1
S-4	X	Alexandria STP	12.4
S-5	X	Westgate STP	12.8
S-6	X	Hunting Creek STP	20.0
S-7	X	Dogue Creek STP	22.3
S-8	X	Pohick Creek STP	24.5

* The RMI's are approximate since the STP's are often located on embayments

II. Conclusions

1. CBOD of the Potomac River samples followed first order kinetics with an average k_e=0.14 day^{-1}.
2. In August, a significant increase in CBOD, between Gunston Cove and Possum Pt., correlated (r=.94) with an algae bloom of *Oscillatoria*.
3. NOD of Potomac River samples between Hains Point and Ft. Washington, (peak NOD area) followed first order kinetics with an average k_e=0.14 day^{-1}. The exceptional samples had significant lag times resulting in S-shaped or consecutive S-shaped D.O. depletion curves. These samples were limited to the algal bloom area and to samples from the Chain Bridge area which had low NOD_{20} (2.0 ppm average).
4. In general, the NOD_5 represented about one-third of the BOD_5 of the river samples and therefore, estimates of $CBOD_5$ from BOD_5 values are prone to error unless a nitrification inhibitor is employed.
5. The $CBOD_{20}$ represented 68% of the river $demand_{20}$.
6. The CBOD of the STP effluents followed first order kinetics with an average k_e=0.17 day^{-1}.
7. The $CBOD_{20}$ represented 31% of the STP effluent $demand_{20}$.
8. The NOD for the STP effluents had a significant lag time resulting in S-shaped or consecutive S-shaped depletion curves. This lag time was probably an artifact, since nitrification in the receiving waters was immediate.
9. The NOD_{20} observed for river samples did not significantly differ from (TKN-N x 4.57) which suggests:

II. Conclusions (con't)

a. Nitrification was essentially complete after 20 days of incubation.

b. The nitrification inhibitor 2-chloro-6 (trichloromethyl) pyridine (common name nitrapyrin), gave accurate NOD results.

c. The NOD observed was due to autotrophic bacteria since the inhibitor was specific for Nitrosomonas spp.

10. The relation $CBOD_{20} = 1.85\ CBOD_5$ held consistently for the Potomac River samples and, with the use of nitrapyrin, short term experiments may yield adequate estimates of ultimate demand via the relation: $UBOD \simeq 1.85\ CBOD_5 + 4.57\ (TKN\text{-}N)$.

III. Procedure

BOD: The BOD test employed was that outlined in Standard Methods APHA 14th edition[1]. Dilutions were made for the S.T.P. samples using BOD bottles, that were within ± 1% of 300 ml, as volumetric flasks. S.T.P. samples were diluted with APHA dilution water; seeded using 1 ml per bottle of stale raw-settled S.T.P. influent; and dechlorinated. All samples were purged for 15 seconds using purified oxygen and a Fisher gas dispersion tube to obtain an initial DO of 10-15 ppm.

DO: All dissolved oxygen measurements were made using a YSI BOD probe #5750 and a YSI model #57 meter. These were calibrated against the Winkler (azide modified) method[1].

Nitrification: The nitrification inhibitor (Hach Chemical Co. #2533) was dispensed, using a powder dispenser, directly into the BOD bottles. This allowed quick and uniform additions of the inhibitor. Two bottles were filled with each sample; one received the inhibitor and represented CBOD and the uninhibited bottle expressed total BOD. The NOD was determined by difference.

Nitrogen-Series: TKN-N was analyzed by the automated phenate method[1]. The NO_2-N + NO_3-N was analyzed by the automated cadmium reduction method[1].

IV. Oxygen Demand in the Potomac River Samples

A. Biochemical Oxygen Demand-Carbonaceous

1. General Discussion

Biochemical oxygen demand is a bioassay procedure concerned with the utilization of oxygen in the biochemical oxidation (respiration) of organic material. This test is one of the most widely used measures of organic pollution, applied both to surface and waste waters. The BOD test has been relied upon in the design of waste treatment plants and to establish standards for effluent discharges. One of the primary disadvantages of this test is that as a bioassay it reflects biological variability. The test is not a relatively simple assay whereby pure strains of bacteria interact with a well-defined media, but involves monitoring a complex and changing population of microorganisms (bacteria, protozoa, fungi, algae, etc.), as they respire in a changing mixture of organic matter. Interlaboratory studies have established its precision on synthetic samples to be ± 20% at $\simeq$ 200 ppm BOD[2]. The accuracy of the test is difficult to assess since the results obtained for "standard solutions" vary markedly with the seed employed[1].

2. Standard BOD_5 Test

The standard method of BOD measurements, adopted by APHA[1], is a five-day test at 20°C in the dark. The five-day incubation period was selected to maximize that portion of the oxygen demand associated with heterotrophic respiration (oxidation of carbon compounds) and, at the same time, minimize the oxygen demand of autotrophic organisms, primarily nitrifying bacteria. The basis for this method selection rests upon the generally observed 10-15 day lag in oxygen uptake associated with the growth of nitrifying bacteria in sewage samples. This assumption was found to be erroneous for Potomac River samples.

The standard BOD_5 test was designed to provide the biota with the macronutrients and oxygen necessary for growth, such that the rate of utilization of organic material will be limited only by the amount and nature of the organic material present. In comparison to a long-term test of 20 or 30 days, the short-term test is more severly dependent upon the number and type of biota introduced (seed) and the temperature of incubation. These factors will affect the kinetics of respiration. In essence the standard BOD_5 test for sewage effluents was not designed to give accurate rate estimates, but its use as a best estimate remains because of the absence of an alternative. BOD tests of river water involved no dilution nor seeding and may have the best correlation with actual river rates, since the least manipulation of the sample is involved. Because the kinetics of the process are largely avoided when measuring plateau values, which are not measureably affected by seed conditions or temperature value between 4 and $20^{\circ}C$[4], the ultimate oxygen demand has been cited as a more practical parameter for judging the potential pollution load[3].

3. CBOD/First Order Kinetics

The kinetics of the carbonaceous BOD observed during this study were first order. The observed oxygen utilization fell off exponentially with time, and approached an ultimate asymptote. The first order characteristic is thought to be the summation of many different reaction rates of the gamut of material expected in waste and river samples.

The expression relating the <u>remaining</u> oxygen demand L, at time t is given by:

$$\frac{-dL}{dt} = k\ Lo \qquad \text{equation \#1}$$

such that the rate at any instant is proportional to the amount of BOD yet to be expressed. Lo is the intial remaining oxygen demand (at t=o) or ultimate demand and k is the deoxygenation rate constant, day^{-1}.
Rearranging and integrating equation #1

$$-\int_{Lo}^{L} \frac{dL}{Lo} = k \int_{t_o}^{t} dt$$

where $t_o = 0$,

$$= -(\ln L - \ln Lo) = kt$$

$$\text{or } \ln L = \ln Lo - kt \qquad \text{equation \#2}$$

The - kt term can be expressed as $\ln e^{-kt}$, since $\ln e^X = X$, and equation #2 becomes

$$\ln L = \ln Lo + \ln e^{-kt}$$

or the familar expression

$$L = Lo\ e^{-kt} \qquad \text{equation \#3}$$

However, the BOD test actually involves the measurement of oxygen consumption rather than the amount left to be depleted, so a new variable y (oxygen depletion) is introducted such that

$$y = Lo - L$$

and substitution into equation #3 yields

$$y = Lo\ (1-e^{-kt}) \qquad \text{equation \#4}$$

The average k_e value reported [5] for the Thames River STP effluent samples was 0.234 day^{-1} which results in

$$y/_{Lo} = (1-e^{(-.234)(5)})$$

or $\quad Lo = 1.45\ y$

or $\quad$ BOD ultimate = 1.45 x BOD_5

It should be cautioned that the equivalent expression

$$y = Lo\ (1-10^{-k't}) \qquad \text{equation \#5}$$

is often employed with k=k'x2.303

The observed Potomac River samples' $CBOD_5$ and $CBOD_{20}$ data, included in Table #2, gave the following best fit function:

$$CBOD_{20} = 1.85\ CBOD_5$$

with a correlation coefficient of 0.945 based upon 53 data pairs.

4. Thomas Graphical Determination of BOD Constants

All data points (6 or 7 readings per sample over the 20 day incubation period) were also used to give the best available estimate of k_{10} and L by using the Thomas Graphical Determination[6,7]. This method relies upon the observation that the relation $(1-10^{-kt})$ is very similar to $2.3\ kt\ [1 + (\frac{2.3}{6})\ kt]^{-3}$

such that by using equation #5

$$y = L_o 2.3\ kt\ [1 + (\frac{2.3}{6})\ kt]^{-3}$$

or

$$\left(\frac{t}{y}\right)^{1/3} = \frac{1}{(2.3L_0k)} + \frac{(2.3k)^{2/3}}{(6L_0)^{1/3}}\,t \quad \text{equation \#6}$$

A plot of $\left(\frac{t}{y}\right)^{1/3}$ vs t yields a linear relation with slope

$m = \frac{(2.3k)^{2/3}}{(6L_0)^{1/3}}$ and intercept $b = \frac{1}{(2.3kL_0)}1/3$.

BOD k_{10} and L values can be determined from equation #6 as follows:

$$\frac{m}{b} = \frac{\frac{(2.3k)^{2/3}}{(6L_0)^{1/3}} \quad \text{slope}}{\frac{1}{(2.3kL_0)^{1/3}} \quad \text{intercept}}$$

$$\frac{m}{b} = \frac{(2.3)^{2/3} \times (2.3)^{1/3} \times k^{2/3} \times k^{1/3}}{6}$$

or

$$k = \frac{2.61m}{b}$$

Also since $b = \left(\frac{1}{2.3kL_0}\right)^{1/3}$ it follows that $L_0 = \frac{1}{2.3b^3k}$.

The end result is that the two variables L_0 and k_{10} are related to a close approximation to y and t by two simple equations which allow their solution.

To facilitate the calculation of Thomas constants, a computer program was written to compute the k_{10} and L_0.

The results are compiled in Table #2. The average (n=43) k_{10} value observed for river CBOD's was k_{10} = 0.062 days^{-1} or k_e = 0.14 days^{-1}. The correlation coefficients (.30-.99):

$$y = L_0\ (1-10^{-kt}) \simeq 2.3kt\ \left(1+ \frac{2.3kt}{6}\right)^{-3}$$

suggests first order kinetics. The value predicted by the Dynamic Estuary Model[8] (DEM) for the deoxygenation rate constant, k_e, of CBOD's at 20°C was 0.17 days^{-1}.

DATE - STA	THOMAS GRAPHICAL DETERMINATION k_{10}	L_o		$CBOD_5$	$CBOD_{20}$
July 20 - P8	0.070	5.41		3.0	5.0
1	0.049	6.76		3.0	6.0
3	0.057*	8.67	1 lag phase	5.2	8.2
4	0.065	6.51		2.6	5.9
5	0.062	8.40		4.4	7.6
6	0.035*	11.78	1 lag phase	5.3	9.7
7	0.053	8.80		4.2	7.9
8-A	0.073	6.85		4.0	6.2
10	0.069	6.69		3.8	6.2
11	0.051	7.99		3.8	6.9
July 27 - P8				-	-
1	0.058	3.85		1.8	3.5
3	0.067	5.62		3.0	5.1
4	0.056	4.67		2.3	4.1
5	-	-		3.0	5.1
6	0.041	10.18		4.0	8.9
7	-	-		-	-
8-A	0.001*	15.60	1 lag phase	3.1	6.4
10	0.065	5.61		3.0	5.1
11	0.020*	7.91		1.9	4.6
Aug. 3 - 1	.071	4.39		2.3	4.1
3	.018*	10.51	1 lag phase	3.0	5.1
4	.066	7.04		3.7	6.6
5	.066	5.93		3.2	5.2
6	.083	5.98		3.5	5.3
7	.055	7.31		3.6	6.5
8-A	.060	8.26		3.9	7.8
10	.055	7.02		3.2	6.4
11	.057	6.43		2.9	6.2
Aug. 24 - P8	.059	6.15		3.1	5.8
1	.078	4.68		2.6	4.3
3	.067	4.46		2.2	4.2
4	.075	6.19		3.6	5.7
5	.066	9.28		5.2	8.6
6	.065	8.66		4.3	8.0
7	.052	10.40		4.6	9.4
8-A	.032*	20.93		7.6	15.4
10	.032*	23.78	8/24 bloom	6.6	17.3**
11	.012*	22.38	~ 300 ppb chloro a	2.8	9.0**
			Algae major contributor		

TABLE # 2 (con't) CBOD RIVER

THOMAS GRAPHICAL DETERMINATION

DATE - STA	k_{10}	L_o		$CBOD_5$	$CBOD_{20}$
Aug. 31 - P8	.058	4.17		2.1	3.8
1	.061	4.65		2.4	4.3
3	.014*	13.80	1 lag phase	3.2	5.7
4	-	-		3.8	6.5
5	.053	7.59		3.7	6.7
6	.091	8.17		5.2	7.2**
7	.062	10.00		5.1	9.2
8-A	.050	12.54		5.2	11.1
10	.055	12.98		6.3	11.9
11	.059	9.48		4.6	8.7
Sept. 8 - P8	.043	5.25		2.0	4.5
1	.069	4.91		2.6	4.5
3	.056	5.31		2.5	5.0
4	.081	8.01		4.8	7.4
5	.056	9.76		4.8	8.8
7	.071	4.80		2.6	4.5
8-A	.065	6.35		3.2	6.1
10	.018*	14.66	1 lag phase	3.9	7.3
11	.035*	8.72		3.1	6.9

* Not included in calculation of average k_{10} due to their exceptionally low correlation coefficients and lag periods in growth

** Deleted from calculation of $CBOD_5/CBOD_{20}$

k_{10}:

n = 43
average = .062
s.d. = .010

The total BOD for the river samples (Table #3) also followed first order kinetics with correlation coefficients over the range of (1.000 to .156) with an average (n=50) k_{10} of 0.054 day^{-1}. This rate corresponds to an expression of 47% of the ultimate BOD after 5 days such that: $BOD_{20} = 2.1 \times BOD_5$

An oxygen depletion curve is included in Figure #2.

5. Temperature Effects Upon Reaction Rates

Any statement concerning the observed B.O.D. reaction rates should take into consideration the potential error due to fluctuation in the incubation temperature. If it is assumed that over a narrow range biochemical reaction rates tend to increase, as do strictly chemical reactions (endothermic), with increasing temperature, then the effect of temperature upon the rate of these reactions may be approximated by the Arrhenius equation[9]: $k = A_e{}^{-Ea/RT}$

were A is the frequency factor or pre-exponential factor ($time^{-1}$); Ea is the activation energy, (energy/mole); T is temperature in ^{0}Kelvin and R is the ideal gas constant (energy x temp x mol^{-1}).

Taking the natural log:

$$\ln k = \frac{-Ea}{RT} + \ln A$$

and differentiating with respect to temperature:

$$\frac{d \ln k}{d T} = \frac{d \ln A}{d T} - \frac{d \frac{Ea}{RT}}{d T}$$

but A, Ea and R are all constant with respect to T.

or: $$\frac{d \ln K}{d T} = \frac{-Ea}{R} \frac{d T^{-1}}{d T} = \frac{Ea}{RT^2}$$

TABLE # 3 BOD RIVER

DATE - STA	k_{10}	L_o	
July 20 - P8	.037	9.10	
1	.032	10.95	
3	.058	13.27	
4	.027	18.31	
5	.049	21.14	
6	.036*	24.5	1 lag phase
7	.040	14.71	
8-A	.058	10.74	
10	.048	10.59	
11	.051	10.53	
July 27 - P8	-.023*	-2.99	2 lag phases
1	.047	5.73	
3	.060	8.50	
4	.057	10.60	
5	.047	11.87	
6	.059	16.45	
7	.041	14.08	
8-A	.003*	100.0	1 lag phase
10	.053	7.95	
11	.023	12.75	
Aug. 3 - P8	.105	2.38	
1	.081	5.85	
3	.063	13.99	
4	.079	12.14	
5	.080	11.08	
6	.045	9.45	
7	.030	11.50	
8-A	.049	13.12	
10	.039	12.50	
11	.042	9.17	
Aug. 24 - P8	.045	9.52	
1	.047	7.83	
3	.072	9.01	
4	.081	10.99	
5	.063	12.99	
6	.059	13.00	
7	.049	14.45	
8-A	.011*	62.48	1 lag phase
10	.010*	68.80	1 lag phase
11	-.004*	-63.35	linear

algae ∿ 300 ppb chloro a

r=.999
m=.673
b=-.232

TABLE # 3 (con't) BOD RIVER

DATE - STA	k_{10}	L_o	
Aug. 31 - P8	.063	5.73	
1	.056	5.97	
3	.054*	14.76	1 lag phase
4	--	--	
5	.073	12.77	
6	.075	12.96	
7	.071	14.80	
8-A	.059	17.89	
10	.045	19.62	
11	.044	15.66	
Sept. 8 - P8	.016	13.04	
1	.039	8.11	
3	.066	10.39	
4	.060	18.65	
5	.060	22.81	
6	.066	12.60	
8-A	.062	9.84	
10	.026*	15.10	1 lag phase
11	.023	16.12	

* Not included in calculation of average k due to their exceptionally low correlation coefficients and lag periods in growth

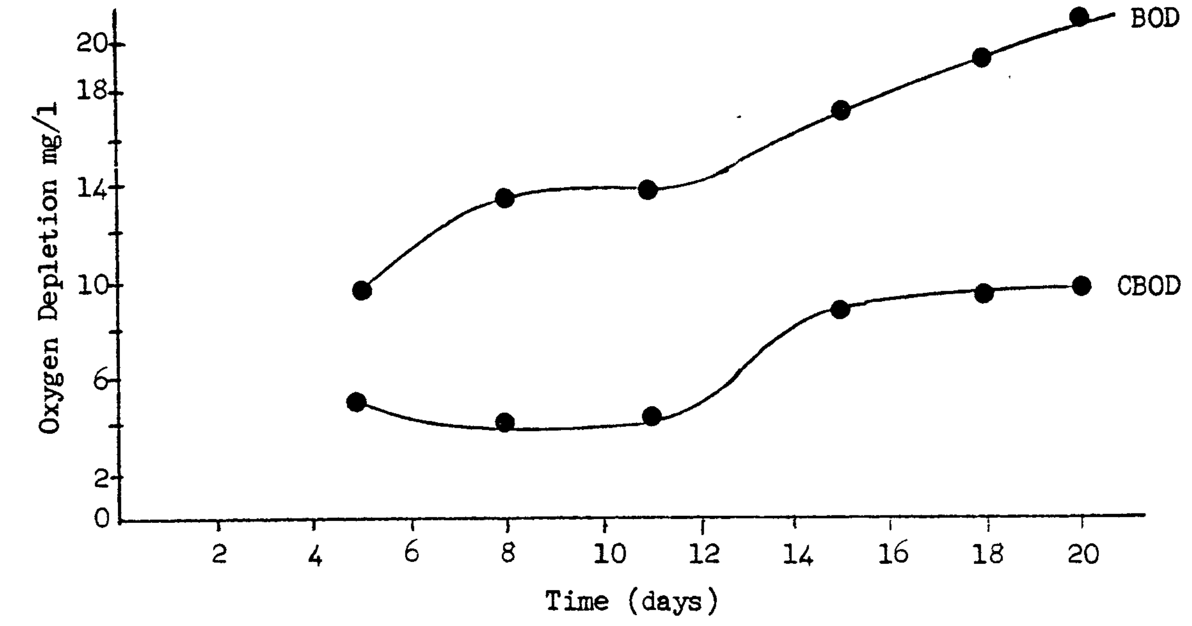
k_{10}:

n = 50
average = .054
s.d. = .017

Figure #2 Depletion Curve for BOD and CBOD

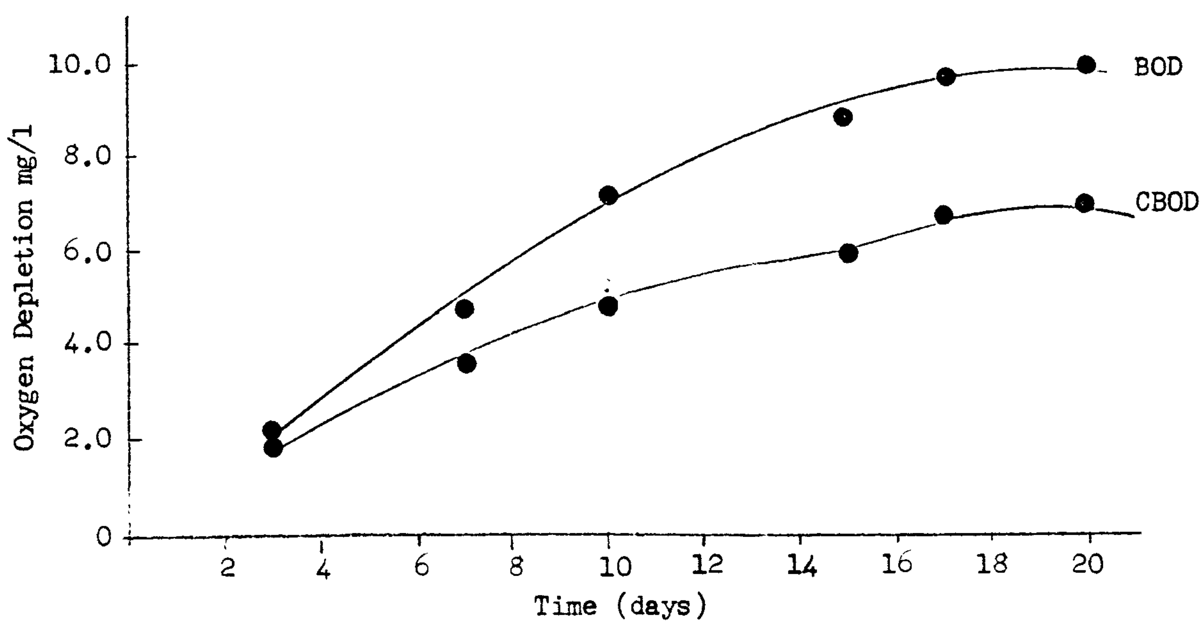
July 20, 1977

Broad Creek Sta. 6



Sept. 8, 1977

Possum Point Sta. 11



Integrating over temperature and rate

$$\int_{k_1}^{k_2} d \ln k = \int_{T_1}^{T_2} \frac{Ea}{RT^2} \, dT$$

$$\ln k_2 - \ln k_1 = \frac{Ea}{R} \int_{T_1}^{T_2} T^{-2} \, dT$$

$$\ln \left(\frac{k_2}{k_1}\right) = \frac{Ea}{R} \left(\frac{1}{T_1} - \frac{1}{T_2}\right)$$

or

$$\ln \left(\frac{k_2}{k_1}\right) = \frac{Ea}{R} \left(\frac{T_2 - T_1}{T_1 T_2}\right) \qquad \text{equation \#7}$$

Because the original assumption is that only a limited temperature range be considered, $T_1 \times T_2$ (in K) is essentially constant. Let $\frac{Ea}{RT_1T_2} = \theta$, which has been termed the temperature coefficient.

Substitution of θ into equation #7.

$$\ln \left({}^{k_2}\!/\!_{k_1}\right) \simeq \theta \left(T_2 - T_1\right) .$$

Experimentally determined θ values have been found to be reasonably constant over narrow temperature ranges with the average value for temperature coefficient over the range 5-25°C being reported[5,10] as 0.056 $^{0}C^{-1}$ and 0.047 $^{0}C^{-1}$. The observed difference between experimental (k_e = 0.143 day^{-1}) and classical (k_e = 0.234 day^{-1})[5,11] rates cannot be explained based soley on fluctuation in incubation temperature. This can be shown by substituting these values into equation #7

$$\ln \left(\frac{.234}{.143}\right) = 0.056 \quad (20 - T_1\,{}^{0}C) \qquad \text{Equation \#8}$$

and solving for T_1

$$T_1 = 11^{0}C.$$

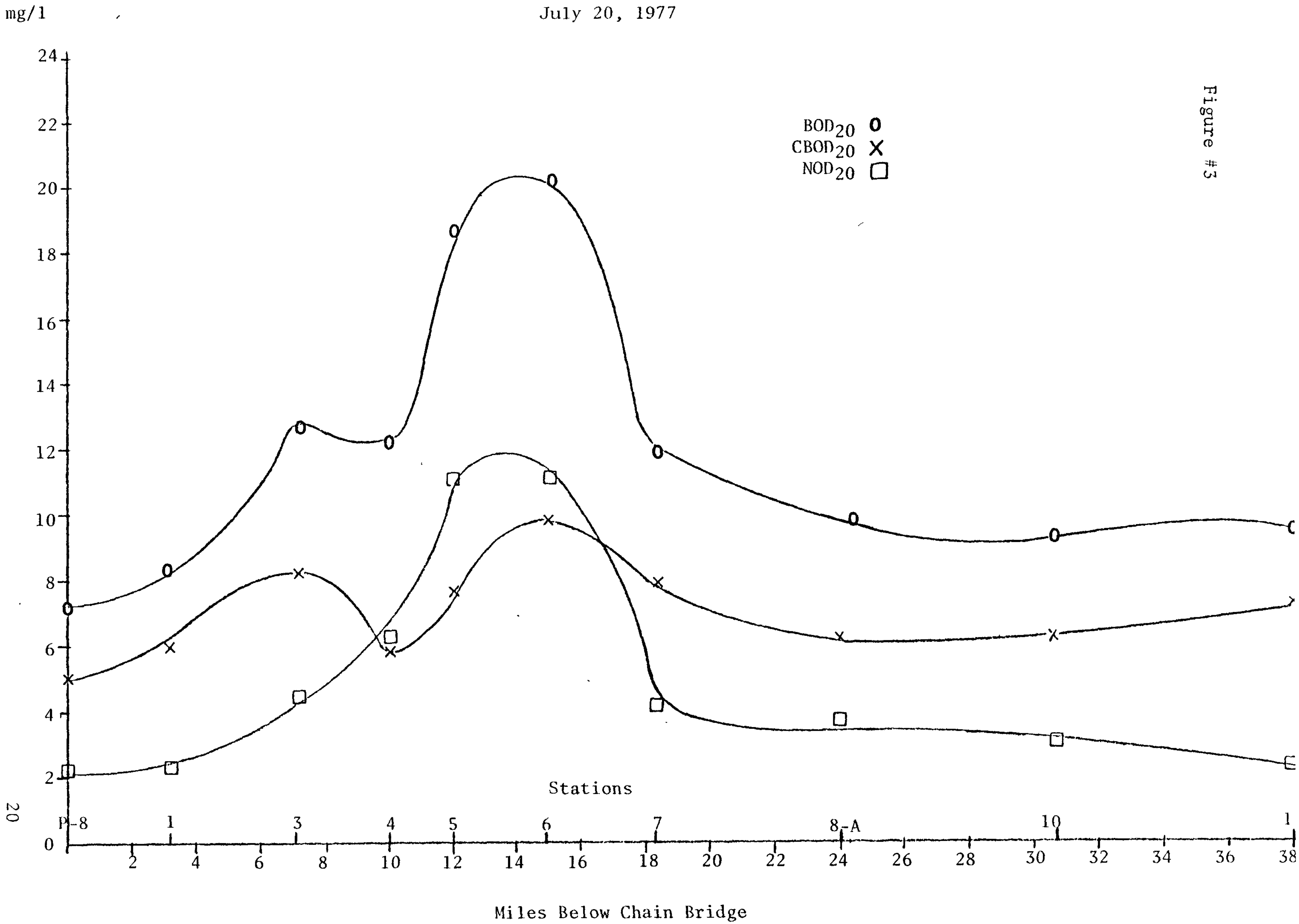
A $9^{0}C$ variation in temperature is necessary to explain the difference in rates. The observed fluctuation of the Jordon Model #818 BOD incubator was 20 $\pm$ $1^{0}C$ (measured with an NBS certified thermometer) during the course of the Potomac Survey. Therefore it may be concluded that the observed rate cannot be explained by temperature fluctuation.

6. Nature and Distribution of CBOD

The distribution of the $CBOD_{20}$ vs RMI and STP locations are compiled in figures 3-8. The peak(s) CBOD area extended from the Memorial Bridge to Gunston Cove, which corresponds to the locations of the major STP's: Arlington; Blue Plains; Alexandria; Westgate; Piscataway; Hunting Creek; Dogue and Pohick.

A second CBOD peak area was observed on August 24 (figure 6) which corresponded to an algal bloom with a chlorophyll a concentration of $\sim$ 300ppb. The chlorophyll a and CBOD data for stations 8-A, 10, and 11 are compiled in Table #4. The high correlation obtained (r=.94 and n=18) suggested this second peak demand area was largely attributable to algal decomposition and/or respiration. The kinetics of the CBOD process for stations 8-A, 10, and 11 were first-order exponential but were abnormally slow (Table #2). These data points were not included in the calculated k_e of 0.143 day^{-1}.

The average $CBOD_{20}$ entering the study area at Chain Bridge was 4.6 ppm while the average NOD_{20} was 2.0 ppm. Figures 3 thru 8 reveal



mg/1
July 20, 1977
BOD20
CBOD20
NOD20
24
22
20
18
16
14
12
10
8
6
4
2
0
Stations
P-8
1
3
4
5
6
7
8-A
10
1
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
Miles Below Chain Bridge

Figure #3

20

July 27, 1977

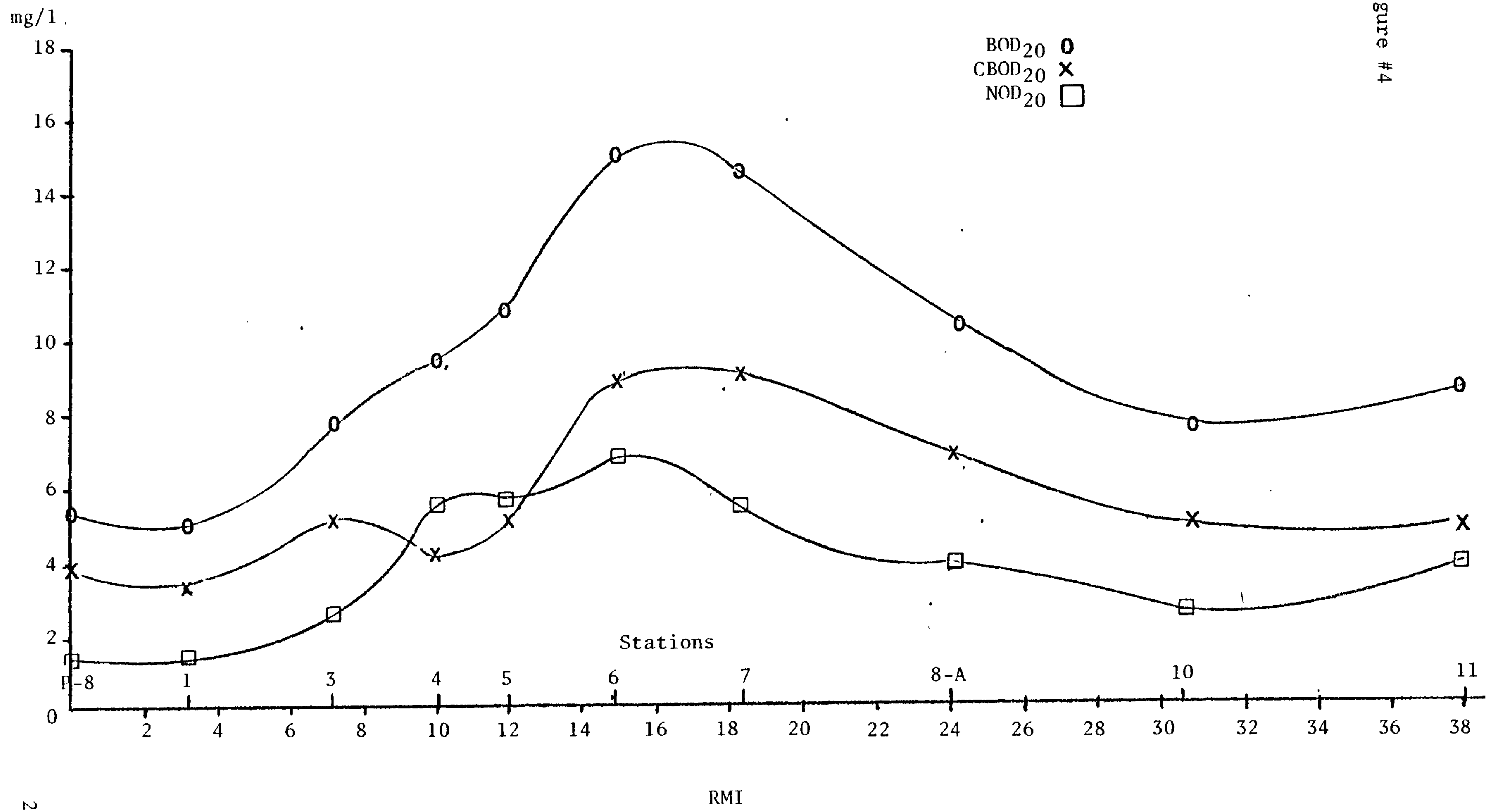


Figure #4

August 3, 1977

Figure #5

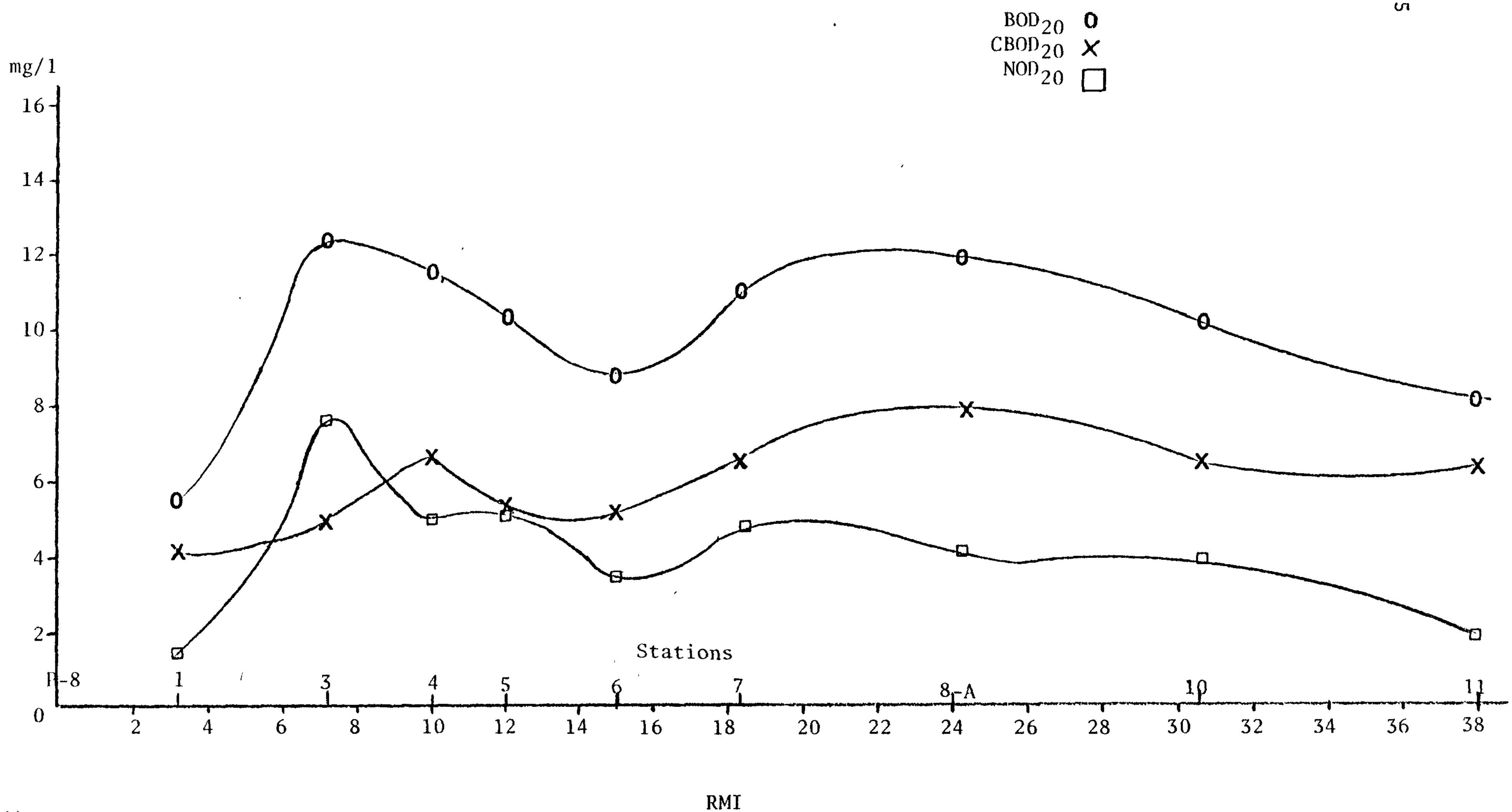
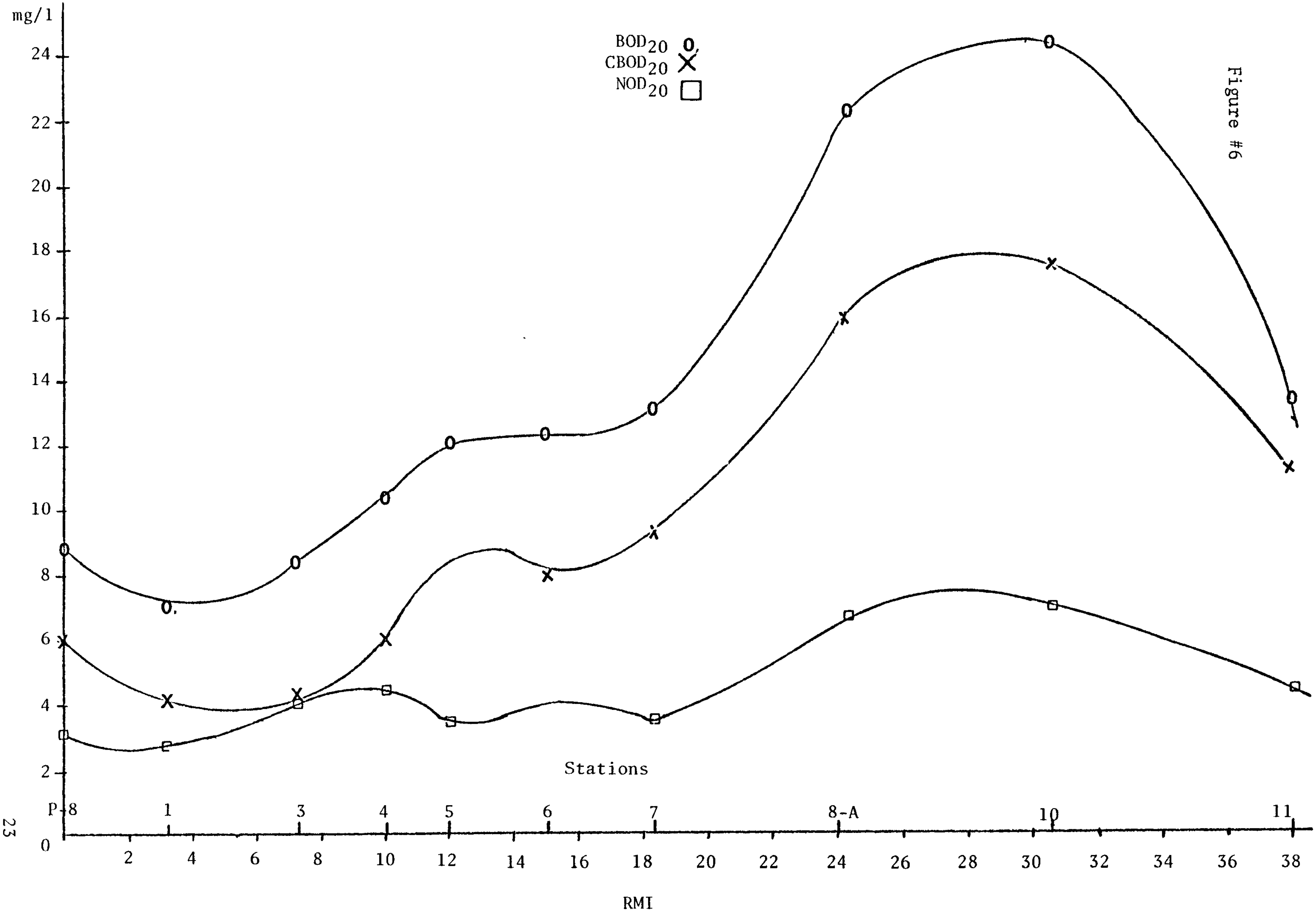


Figure #6

August 24, 1977



August 31, 1977

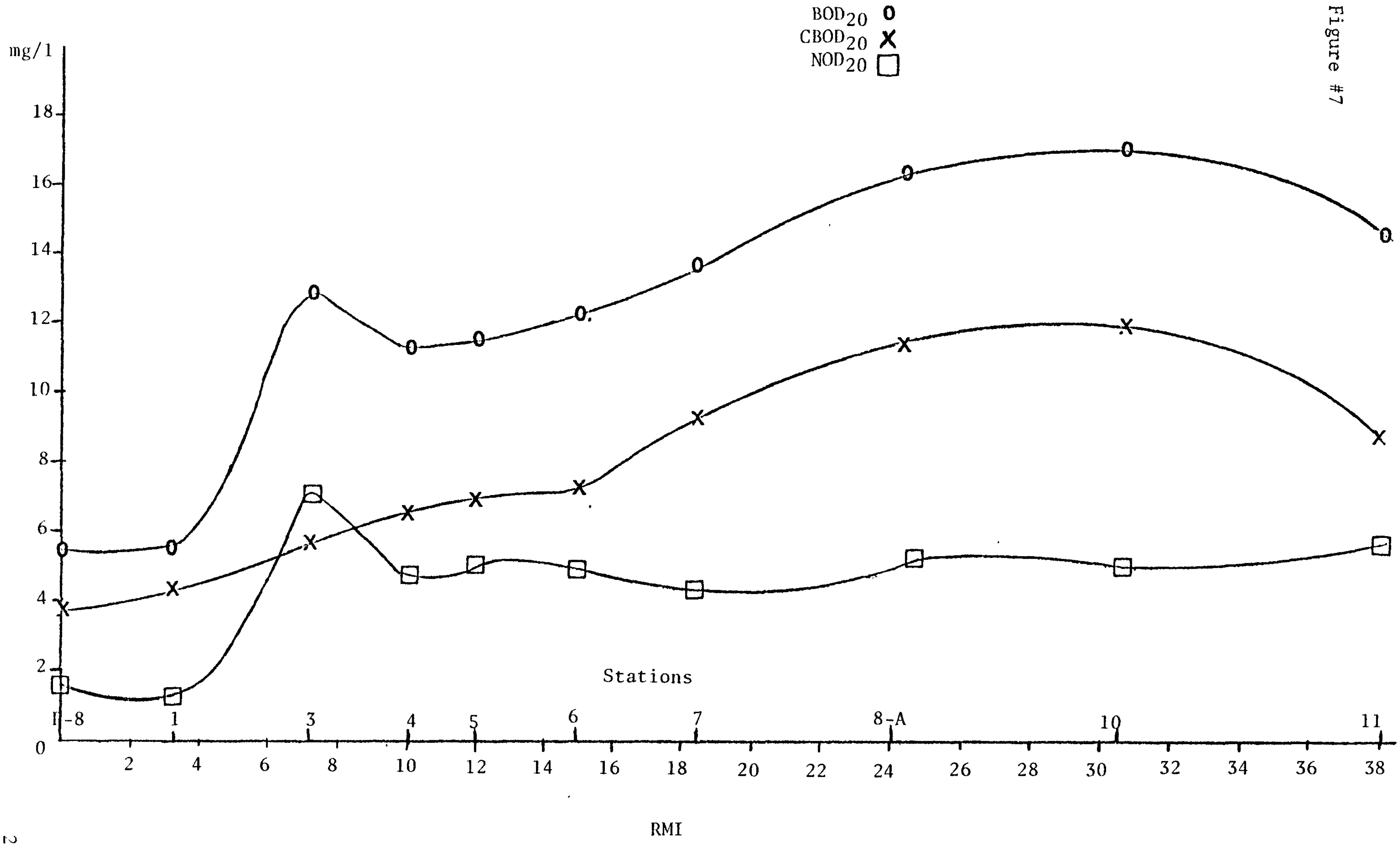


Figure #7

September 8, 1977

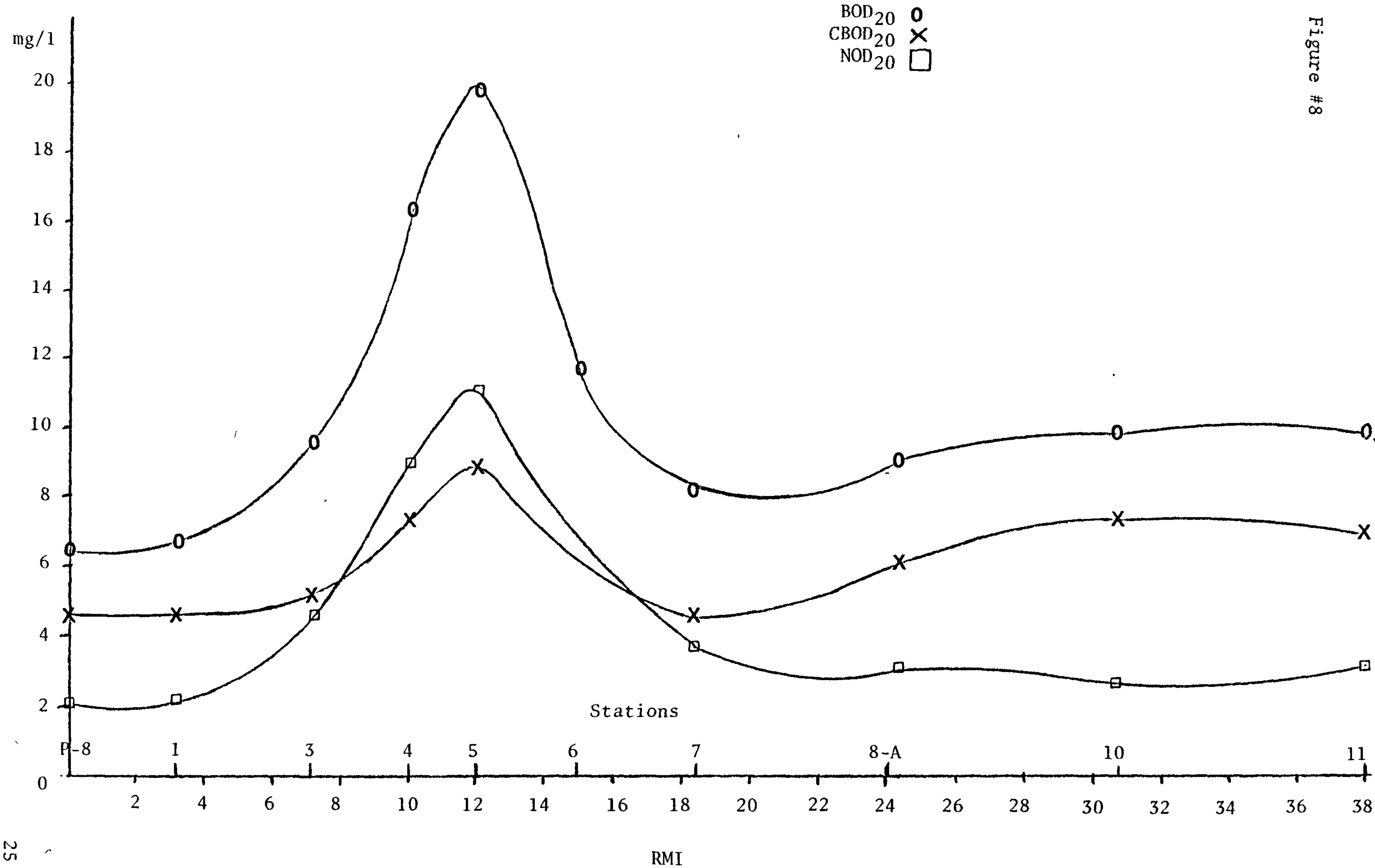


Figure #8

TABLE # 4

Date	Station #	Name	Chlorophyll $\underline{a}$ ppb	$CBOD_{20}$ ppm
July 20	8-A	Gunston Cove	86.2	6.2
	10	Indian Head	81.0	6.2
	11	Possum Point	90.0	7.2
July 27	8-A	Gunston Cove	123.0	6.4
	10	Indian Head	129.0	5.1
	11	Possum Point	112.5	4.6
Aug. 3	8-A	Gunston Cove	103.5	7.8
	10	Indian Head	76.5	6.4
	11	Possum Point	85.5	6.2
Aug. 24	8-A	Gunston Cove	306.0	15.4
	10	Indian Head	312.0	17.3
	11	Possum Point	168.0	9.0
Aug. 31	8-A	Gunston Cove	187.5	11.1
	10	Indian Head	195.0	11.9
	11	Possum Point	148.5	8.7
Sept. 8	8-A	Gunston Cove	85.5	6.1
	10	Indian Head	100.5	7.3
	11	Possum Point	120.0	6.9

n=18
r=.942
m=.046
b=1.907

that CBOD is in general more significant than the NOD for the river samples. This may be attributed to the greater masses of carbon in the system[8]. The average NOD_{20}/BOD_{20} (Table #7) was 0.38, (n=58). The algal bloom area exhibited the same trend which reflects the algae C/N ratio of 4.6 found by elemental analysis. The few exceptions to the dominant CBOD pattern were restricted to river locations adjacent to the sewage plants in the reach from the 14th Street Bridge to Broad Creek. Nitrification was largely completed above the algal bloom area.

B. Biochemical Oxygen Demand - Nitrogenous

1. General Discussion

Nitrification is the conversion of NH_3 to NO_3 by biological respiration. This type of respiration is employed by seven genera of autotrophic nitrifyers as listed in Bergey's manual[12]. However, only *Nitrosomonas spp* and *Nitrobacter spp* are regularly reported by in situ nitrification studies[13]. In general, the treatment of nitrifying river samples with inhibitors specific to *Nitrosomonas* and *Nitrobacter* can be expected to stop all appreciable nitrification[14]. It should be noted that heterotrophic nitrification can also occur whereby NO_2 and NO_3 are formed by reactions that do not involve oxidation. The contribution due to these organisms was not found to be significant in the Potomac River, since a close correlation was observed between the expected NOD (associated with TKN-N) and the measured NOD which was specifically limited to autotrophic bacteria.

2. Bacterial Growth Requirements

Nitrifying bacteria prefer temperatures of 35-40°C but can survive well over the range of 4-45°C[14]. The rate of nitrification increases with increasing temperature throughout the range of 5-35°C[13]. Nitrifying bacteria are more temperature sensitive than heterotrophic bacteria and their contribution to B.O.D. will vary more markedly with temperature. BOD samples assayed during winter months should incorporate a nitrification inhibitor to yield results more relevant to river conditions. The temperature ranges observed during this summer's Potomac survey were very narrow:

Date	Temperature Range °C
July 20	31-29
July 27	28-25
Aug. 3	28-27
Aug. 24	26-27
Aug. 31	30-28
Sept. 8	28-27

Nitrifyers can generally tolerate a pH range of 6-10[14]. The "ideal" values seems to vary with the particular environmental conditions from which the tested bacteria were selected but in general a slightly basic pH seems ideal (∿8.0). At pH levels below 7, the rate of maximum growth was decreased by more than 50%[14]. Dissolved oxygen does not seem to affect the rate of their growth above 0.5ppm.[5,13,14] The average temperature and pH measured over the course of this study were 27.0°C and 7.6 respectively.

The reactions involved in nitrification are as follows:

$$NH_4^+ + 1\tfrac{1}{2}\,O_2 \xrightarrow{\text{Nitrosomonas}} 2H^+ + NO_2^- + H_2O \qquad \text{equation \#9}$$

$$NO_2^- + \tfrac{1}{2}\,O_2 \xrightarrow{\text{Nitrobacter}} NO_3^- \qquad \text{equation \#10}$$

An average pH of 7.6 was found in the Potomac River long term BOD samples. The pk_a of ammonia at 25°C is 9.26[15]. These factors combined with the Henderson-Hasselbach equation:

$$pH = pk_a + \log \frac{base}{acid}$$

establish that NH_4^+ should be used in the preceeding equations and that ammonium (NH_4^+) represents 98% of all ammonia species present.

3. Lag Phase and Growth Characteristics

Nitrosomonas have a maximum growth rate less than that of *Nitrobacter* and heterotrophic bacteria in general have a maximum growth rate nearly double[14] that of autotrophic bacteria (doubling time of 30/hr)[13]. For STP effluent samples an NOD lag time of 10-15 days often occurs due to the slow growth of nitrifying bacteria and the small population initially present. For this reason, nitrogenous oxygen demand is often termed second stage BOD.

Nitrifiers not only have a slower growth rate but also are more fragile than heterotrophic bacteria, resulting in more sporadic results from an NOD experiment than from CBOD tests[13]. The growth of nitrifiers are inhibited by a wide variety of substances as[16]:

halogens; thiourea and thiourea derivatives; halogenated solvents; heavy metals; cyanide; phenol; and cresol.

A study of 52 such compounds known to inhibit nitrification revealed that the inhibition of *Nitrobacter* is less severe than that of *Nitrosomonas*; *Nitrosomonas* representing the weak link in nitrification[17].

Nitrification is a surface phenomenon with much of nitrification occurring in clear, shallow rivers on the surfaces of mud (aerobic), plants, slime, etc[16]. Laboratory experiments involving the incubation of clear-shallow stream samples would not be expected to reflect the extent of in situ nitrification. However in a turbid estuary, such as the Potomac, the surface area of the suspended material is expected to exceed that of the river bed, such that nitrification would be expected to be more significant in the water column. Tests of such water samples should estimate the extent of nitrification actually occurring in the estuary.

4. Stoichiometry of Nitrification

The stoichiometry of the nitrification reactions, equations #9 & #10 dictate that the conversion of 1 gram of nitrogen from ammonia to nitrite utilizes 3.43 grams of oxygen and the conversion of 1 gram of nitrite-nitrogen to nitrate involves the utilization of 1.14 grams of oxygen. However, nitrifying bacteria are autotrophic and as such utilize a portion of the energy derived from nitrogen oxidation to reduce CO_2, their primary source of carbon. The net result is a reduction in the amount of oxygen actually consumed. Short term (0-5 day) experiments,[18,19,20] employing cultures of Nitrosomonas and Nitrobacter have related the depletion of oxygen to the production of nitrite and nitrate with the corresponding O/N ratios of 3.22 and 1.11 determined. However in long term experiments, the decay of these organisms would be expected to exert an oxygen demand approximately equivalent to the oxygen originally generated, resulting in an overall relation not significantly different from 4.57[21].

In Table #5, NOD_{20} derived from long term incubation of river samples was compared to a predicted value based upon 4.57 x TKN-N initially assayed in the sample. A paired t-test established, at a 95% confidence level, that no significant difference existed between these methods of prediction with t=.7 at 57 degrees of freedom. A plot of the predicted NOD (4.57 x TKN-N) vs that observed with laboratory incubation is included in figure #9. The comparison of NOD and TKN x 4.57 vs RMI is included in figures #10 and #12 - #16. The close correlation suggests that:

1. Nitrification was essentially completed after 20 days of laboratory incubation.
2. The inhibitor to nitrification employed, N-serve, gave accurate NOD results.
3. The NOD observed was due to autotrophic bacteria since the inhibitor was specific for *Nitrosomonas*.

Figures #3-8 include the found NOD vs River Mile Index and indicate that nitrification occurs within a short span of the river, between Hains Point and Fort Washington.

A second peak NOD area occurred, as with CBOD, at stations 8-A; 10 and 11 on August 3, 24, and 31. This was thought to reflect the nitrogen contribution associated with the decay of the algae present at these stations. A significant NOD lag time was observed in samples obtained in the algal bloom area.

The changes in NO_2, NO_3, and NH_3 concentration with RMI for samples obtained on July 20 are included in figure #11. They illustrate the classical relation expected during the course of

TABLE # 5 NOD_{20} vs (TKN-N x 4.57)

Date	Station	RMI	NOD_{20} (TCMP)	TKN	NOD (4.57)(TKN)
July 20	P-8	0.0	2.2	.741	3.4
	1	3.4	2.3	.705	3.2
	3	7.6	4.4	.821	3.8
	4	10.0	6.2	2.05	9.4
	5	12.1	11.0	2.495	11.4
	6	15.2	11.1	2.20	10.1
	7	18.4	4.0	1.358	6.2
	8-A	24.3	3.6	1.074	4.9
	10	30.6	3.0	.853	3.9
	11	38.0	2.6	.621	2.8
July 27	P-8	0.0	1.4	.461	2.1
	1	3.4	1.5	.380	1.7
	3	7.6	2.6	.582	2.7
	4	10.0	5.3	.986	4.5
	5	12.1	5.6	1.212	5.5
	6	15.2	6.8	1.301	5.9
	7	18.4	5.5	.897	4.1
	8-A	24.3	3.8	.727	3.3
	10	30.6	2.4	.606	2.8
	11	38.0	3.6	.509	2.3
Aug. 3	P-8	0.0	LA	.438	2.00
	1	3.4	1.4	.358	1.6
	3	7.6	7.3	1.477	6.7
	4	10.0	4.8	1.262	5.8
	5	12.1	5.0	1.298	5.9

TABLE # 5 (con't) NOD_{20} vs (TKN-N x 4.57)

Date	Station	RMI	NOD_{20} (TCMP)	TKN	NOD (4.57)(TKN)
Aug. 3 (con't)	6	15.2	3.3	1.083	4.9
	7	18.4	4.4	.877	4.0
	8-A	24.3	4.0	.734	3.4
	10	30.6	3.8	.684	3.1
	11	38.0	1.8	.546	2.5
Aug. 24	P-8	0.0	3.0	.484	2.2
	1	3.4	2.7	.484	2.2
	3	7.6	4.0	.894	4.1
	4	10.0	4.4	1.378	6.3
	5	12.1	3.4	1.161	5.3
	6	15.2	4.1	1.094	5.0
	7	18.4	3.5	1.119	5.1
	8-A	24.3	6.6	1.269	5.8
	10	30.6	6.8	1.328	6.1
	11	38.0	4.2	.802	3.7
Aug. 31	P-8	0.0	1.6	.472	2.2
	1	3.4	1.2	.400	1.8
	3	7.6	7.1	1.760	8.0
	4	10.0	4.7	1.392	6.4
	5	12.1	5.1	1.264	5.8
	6	15.2	4.9	1.092	5.0
	7	18.4	4.3	.968	4.4

TABLE # 5 (con't) NOD_{20} vs (TKN-N x 4.57)

Date	Station	RMI	NOD_{20} (TCMP)	TKN	NOD (4.57)(TKN)
Aug. 31 (con't)	8-A	24.3	5.2	1.224	5.6
	10	30.6	4.9	1.28	5.5
	11	38.0	5.6	.816	3.7
Sept. 8	P-8	0.0	2.0	.460	2.1
	1	3.4	2.2	.406	1.9
	3	7.6	4.5	1.056	4.8
	4	10.0	8.9	1.43 *	6.5
	5	12.1	11.0	1.83 *	8.4
	6	15.2	--	--	
	7	18.4	3.6	.721	3.3
	8-A	24.3	3.0	.451	2.1
	10	30.6	2.5	.288	1.3
	11	38.0	3.0	.388	1.8

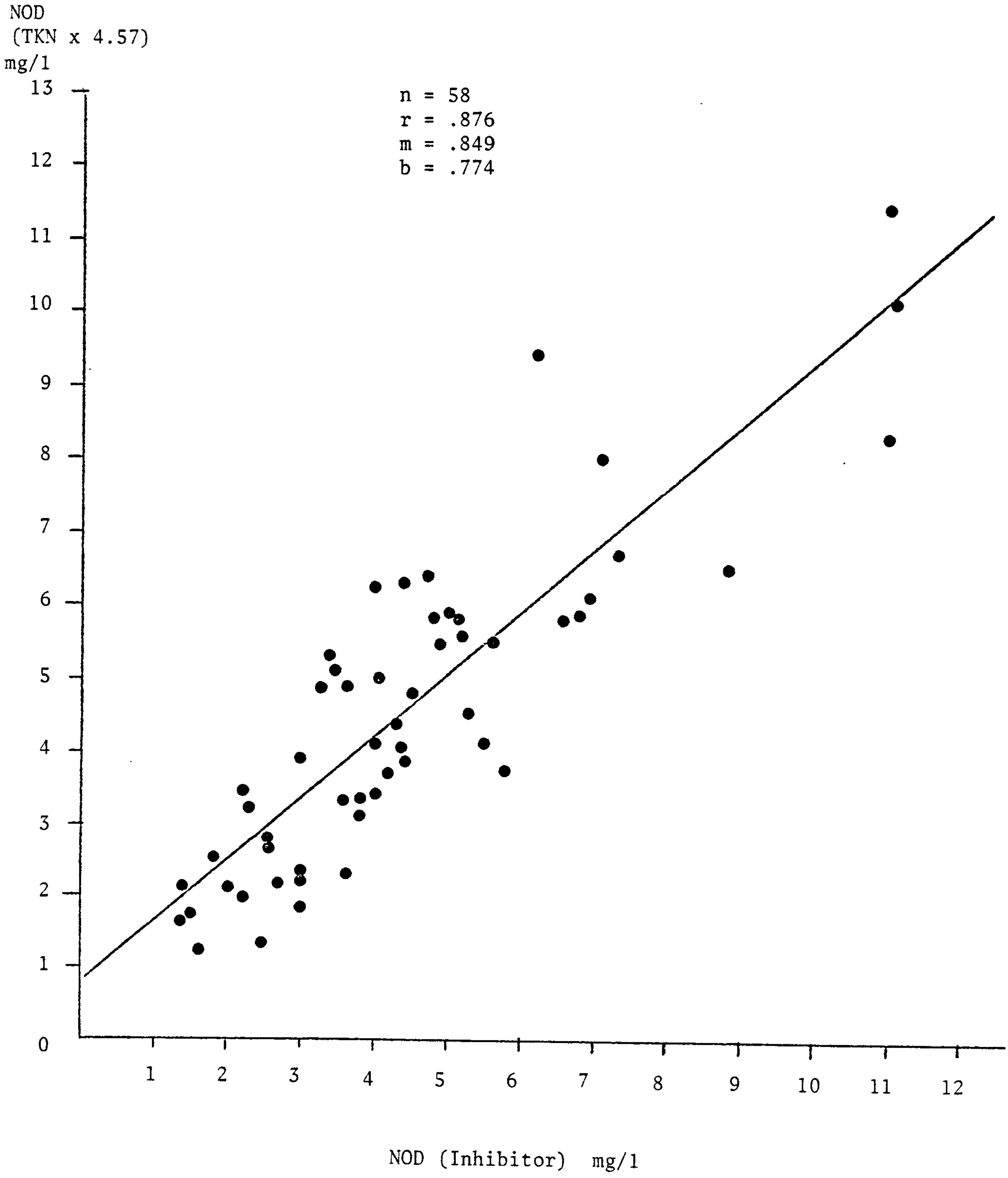
$\bar{d}$ = .0965
Sd = 1.1207
$S\bar{d}$ = .1471
df = 57.00
t = 0.6560

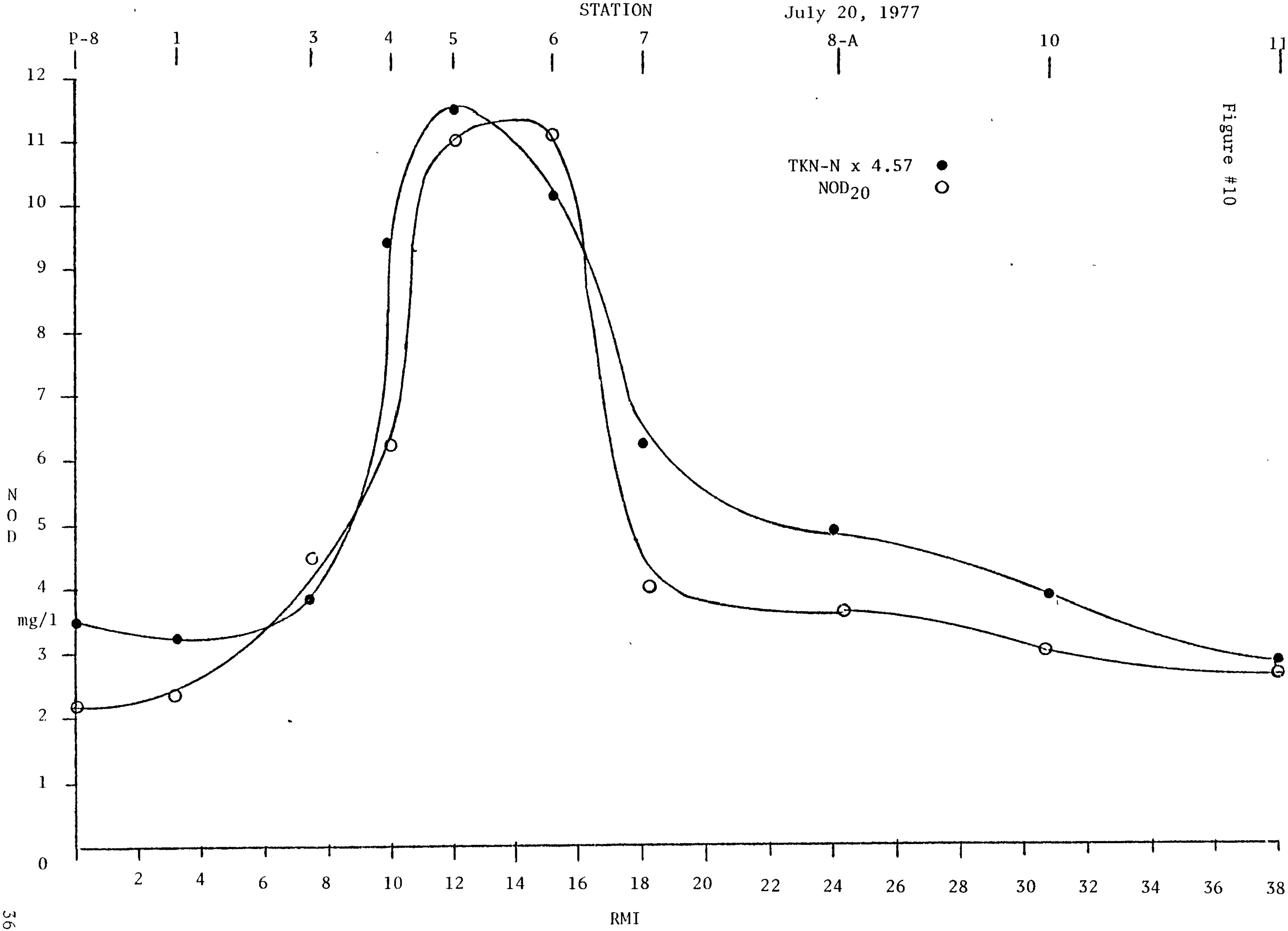
n = 58
r = .876
m = .844
b = .774

* Not included in calculation of r or t
LA = lab accident

Figure #9

NOD_{20} (Inhibitor) vs NOD (TKNx4.57) for River Water Samples



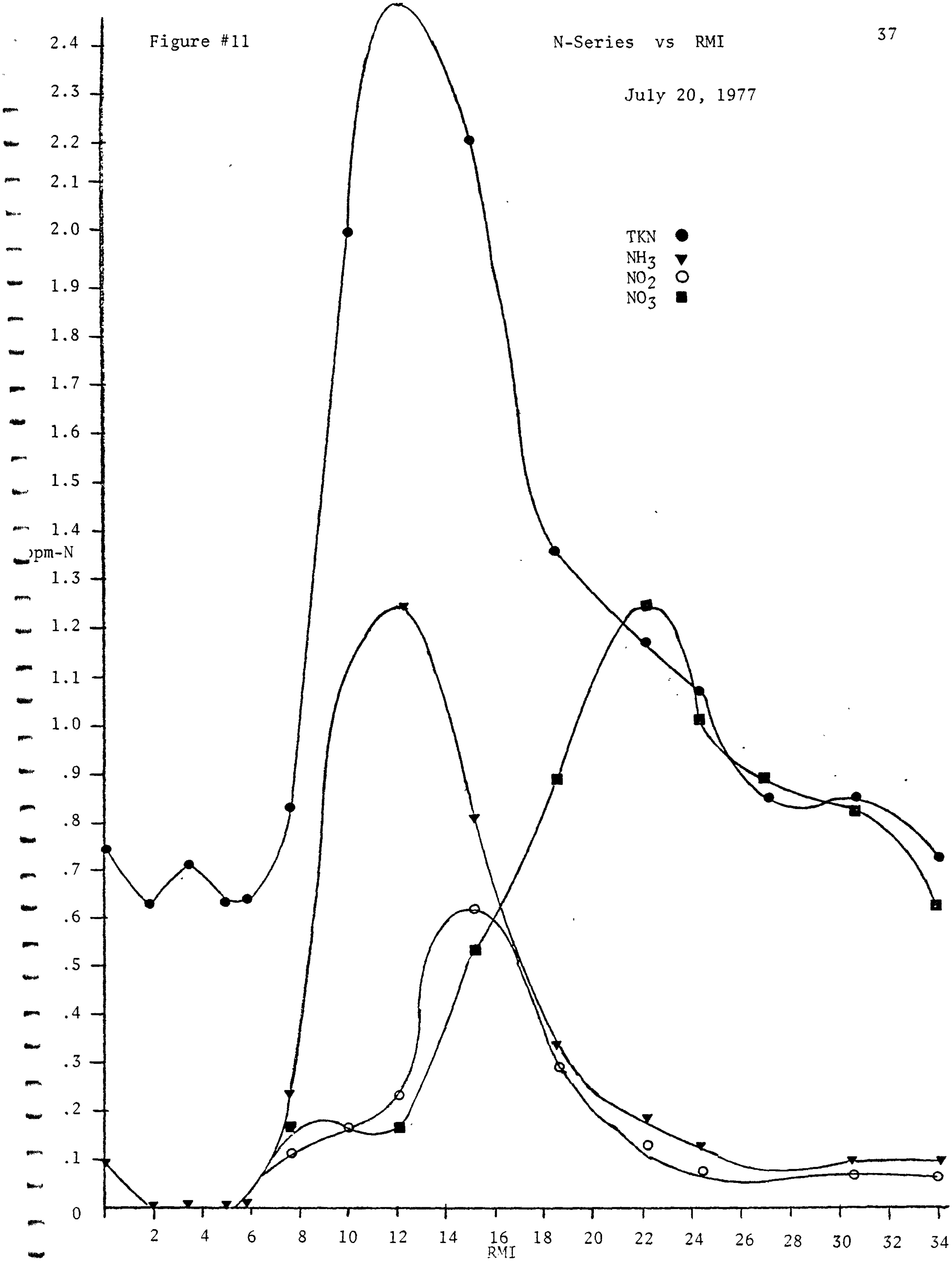


STATION
July 20, 1977
P-8
1
3
4
5
6
7
8-A
10
11
TKN-N x 4.57
NOD20
NOD
mg/l
RMI

Figure #10

Figure #11 N-Series vs RMI

July 20, 1977



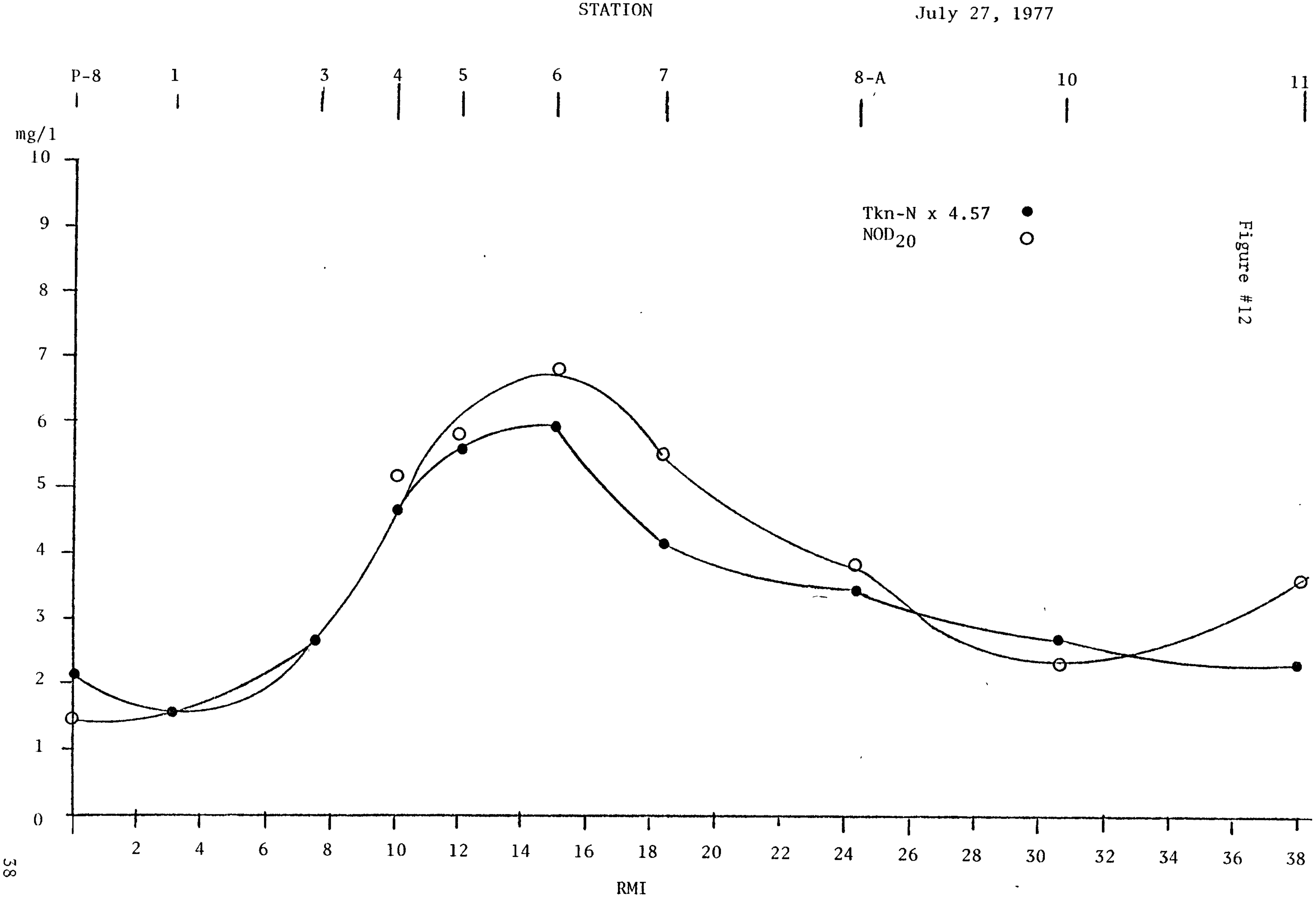

STATION
July 27, 1977
P-8
1
3
4
5
6
7
8-A
10
11
mg/1
Tkn-N x 4.57
NOD_{20}
RMI

Figure #12

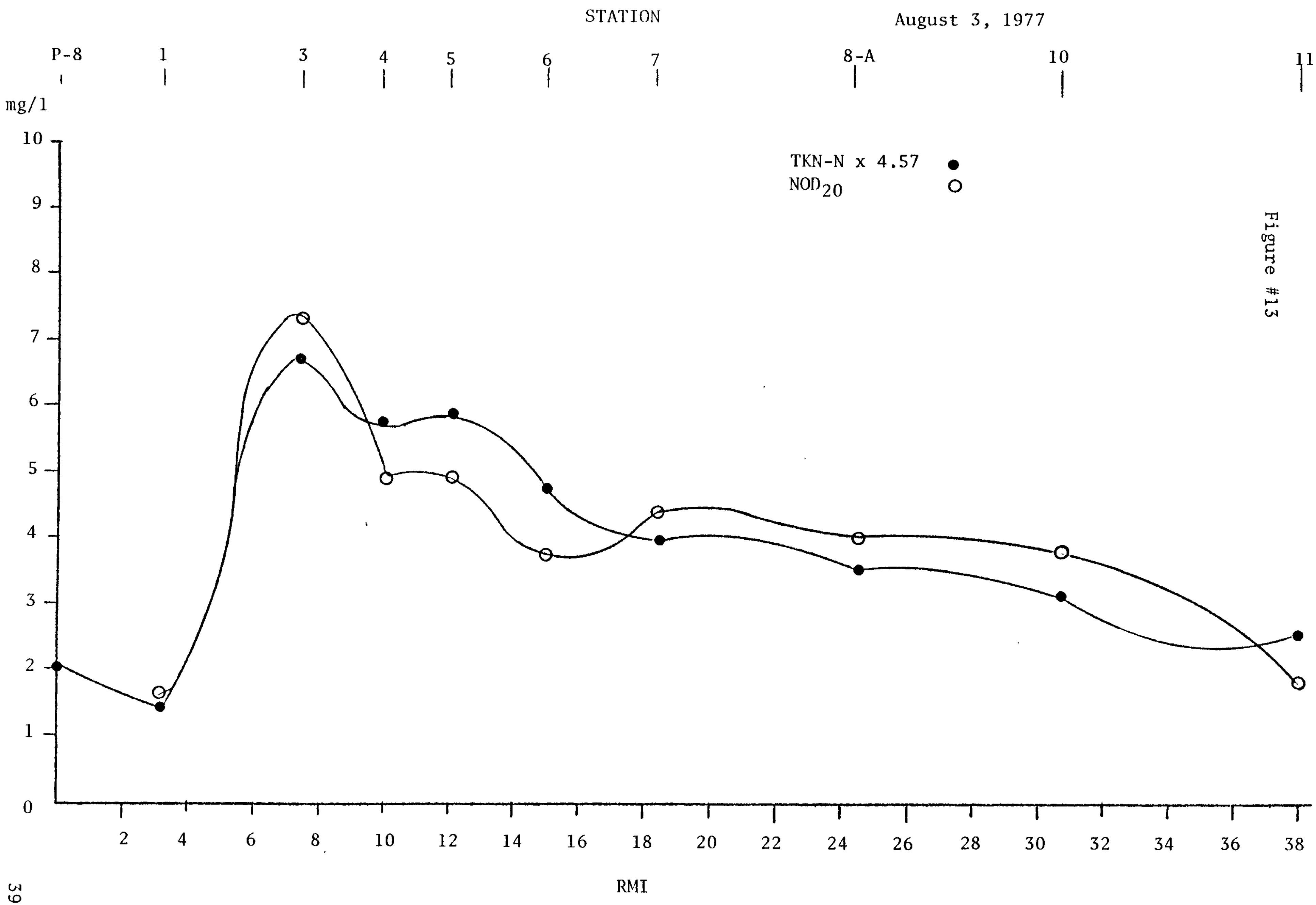
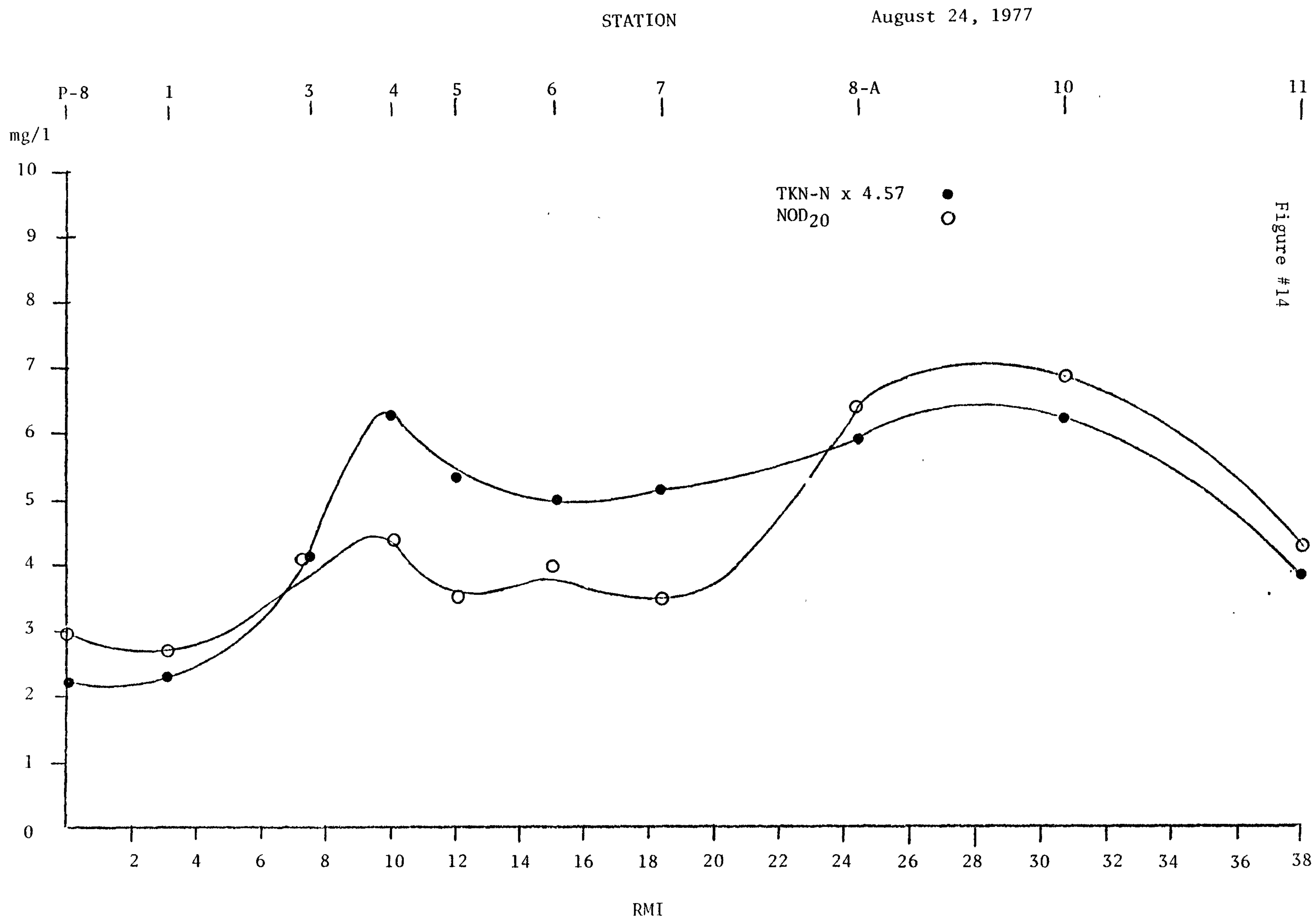

STATION
August 3, 1977
P-8
1
3
4
5
6
7
8-A
10
11
mg/l
10
9
8
7
6
5
4
3
2
1
0
TKN-N x 4.57
NOD_{20}
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
RMI

Figure #13



STATION
August 24, 1977
P-8
1
3
4
5
6
7
8-A
10
11
mg/1
10
9
8
7
6
5
4
3
2
1
0
TKN-N x 4.57
NOD20
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
RMI

Figure #14

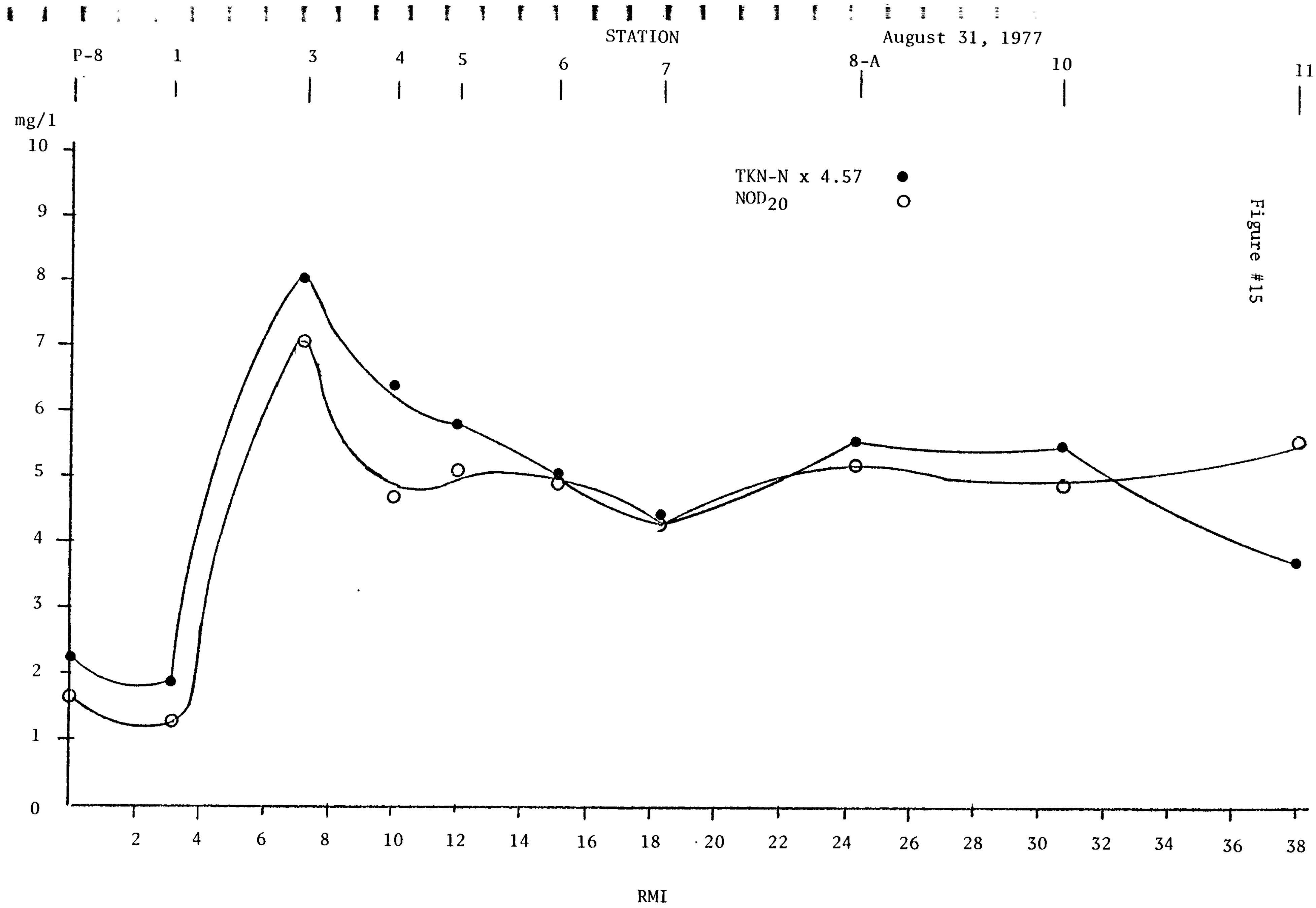

STATION
August 31, 1977
P-8
1
3
4
5
6
7
8-A
10
11
mg/1
10
9
8
7
6
5
4
3
2
1
0
TKN-N x 4.57
NOD20
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
RMI

Figure #15

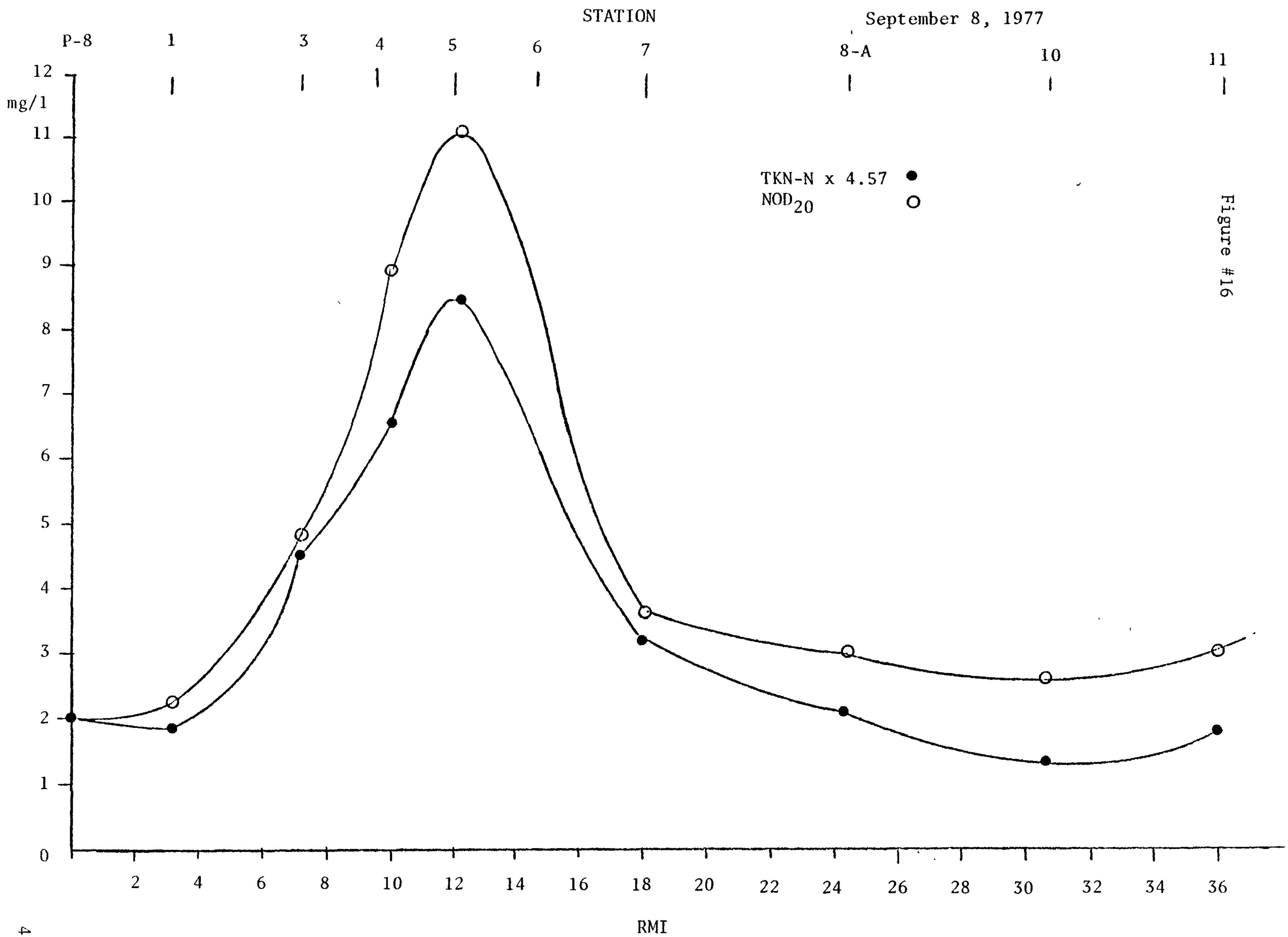

STATION
September 8, 1977
P-8
1
3
4
5
6
7
8-A
10
11
mg/1
TKN-N x 4.57
NOD20
RMI
0
1
2
3
4
5
6
7
8
9
10
11
12
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36

Figure #16

nitrification. The NOD pattern for this slack run (figure #11) is directly associated with a decrease in NH_3 and a corresponding increase in NO_2^- and NO_3^-.

5. Nitrification Kinetics

The kinetics of nitrification for river samples taken between Hains Point and Ft. Washington, the peak area of nitrification associated with the STP effluents, were found to be exclusively first order. The average k_e of 0.14 day^{-1} was observed with a correlation coefficient of 0.91 for n=25 (Table #6). This k value is consistent with the close correlation between NOD and TKN-N x 4.57, since a k_e of 0.14 day^{-1} predicts that 94% of the ultimate NOD will be expressed after 20 days of incubation. The value predicted by the Dynamic Estuary Model (DEM)[8] for the deoxygenation constant of NOD was 0.08 day^{-1}. The standard deviation of 0.02 for the NOD k_e (Table #6) was twice that of the CBOD rate constant and reflects the fragile and sporadic nature of nitrification.

6. Nature and Distribution of NOD

Bracketing the region of exponential NOD are the upper stations at Chain and Key Bridges and lower stations from Gunston Cove to Possum Point. Occasionally these stations had poor correlation to Thomas Plots. The upper stations correspond to a region of low NOD_{20} levels with an average of 2.0 ppm. The lower stations correspond to a region of low NOD_{20} or algal blooms. The data from these stations was plotted as D.O. depletion vs time and two additional classes of kinetics were observed (figure 17). A two-stage or consecutive

TABLE # 6 NOD RIVER

DATE - STA	k_{10}	L_0	r	CURVE CODE	(see figure #17)
July 20 - P8	-.061	-0.178	-.747	S	Low NOD
1	-.560	-.016	-2.39	S	
3	.031	5.19	.83	E	
4	.040	8.03	.784	E	
5	.038	13.47	.966	E	
6	.035	13.07	.942	E	
7	--	--	--	-	
8-A	.029	4.71	.875	E	
10	.001	65.45	.048	S	Low NOD
11	.051	2.46	.871	E	
July 27 - P8	--	--	--	-	
1	.107	1.49	.897	E	
3	.042	3.47	.700	E	
4	.058	5.93	.992	E	
5	--	--	--	-	
6	.071	7.36	.991	E	
7	--	--	--	-	
8-A	-.000	-361.09	-.009	S	Low NOD
10	.102	1.93	.901	E	
11	.027	5.16	.855	E	
Aug. 3 - 1	.103	1.53	.949	E	
3	.083	8.00	.982	E	
4	.094	5.23	.961	E	
5	.090	5.20	.928	E	
6	.024	4.60	.793	E	
7	.030	6.21	.944	E	
8-A	0.033	5.13	.895	E	
10	-.052	4.08	-.746	C	Low NOD
11	-.025	-1.02	-.704	S	
Aug. 24 - P8	.015	5.56	.740	C	
1	-.022	-1.63	-.823	S	
3	0.076	4.55	.992	E	
4	0.089	4.83	.991	E	
5	0.053	3.79	.959	E	
6	0.045	4.54	.972	E	
7	0.030	4.75	.700	E	
8-A	0.023	-4.08	-.263	S	Algae 300ppb
10	0.009	-13.38	-.188	S	
11	0.002	45.92	-.022	C	

TABLE # 6 (con't) NOD RIVER

DATE - STA	k_{10}	L_0	r	CURVE CODE (see figure #17)	
Aug. 31 - P8	.068	1.60	.871	E	
1	--	--	--	-	
3	.077	7.81	.964	E	
4	--	--	--	-	
5	.095	5.60	.989	E	
6	.043	5.41	.900	E	
7	.090	4.95	.992	E	
8-A	.073	5.63	.935	E	
10	.009	15.59	.229	C	
11	.014	9.92	.487	C	Algae 200ppb
Sept. 8 - 1	-.056	-.22	-.654	S	
3	.077	5.12	.997	E	
4	.036	12.37	.714	E	
5	.063	13.00	.925	E	
7	.067	3.79	.930	E	
8-A	.054	3.51	.981	E	
10	.039	2.73	.734	C	Low NOD
11	-.011	-5.63	-.305	S	

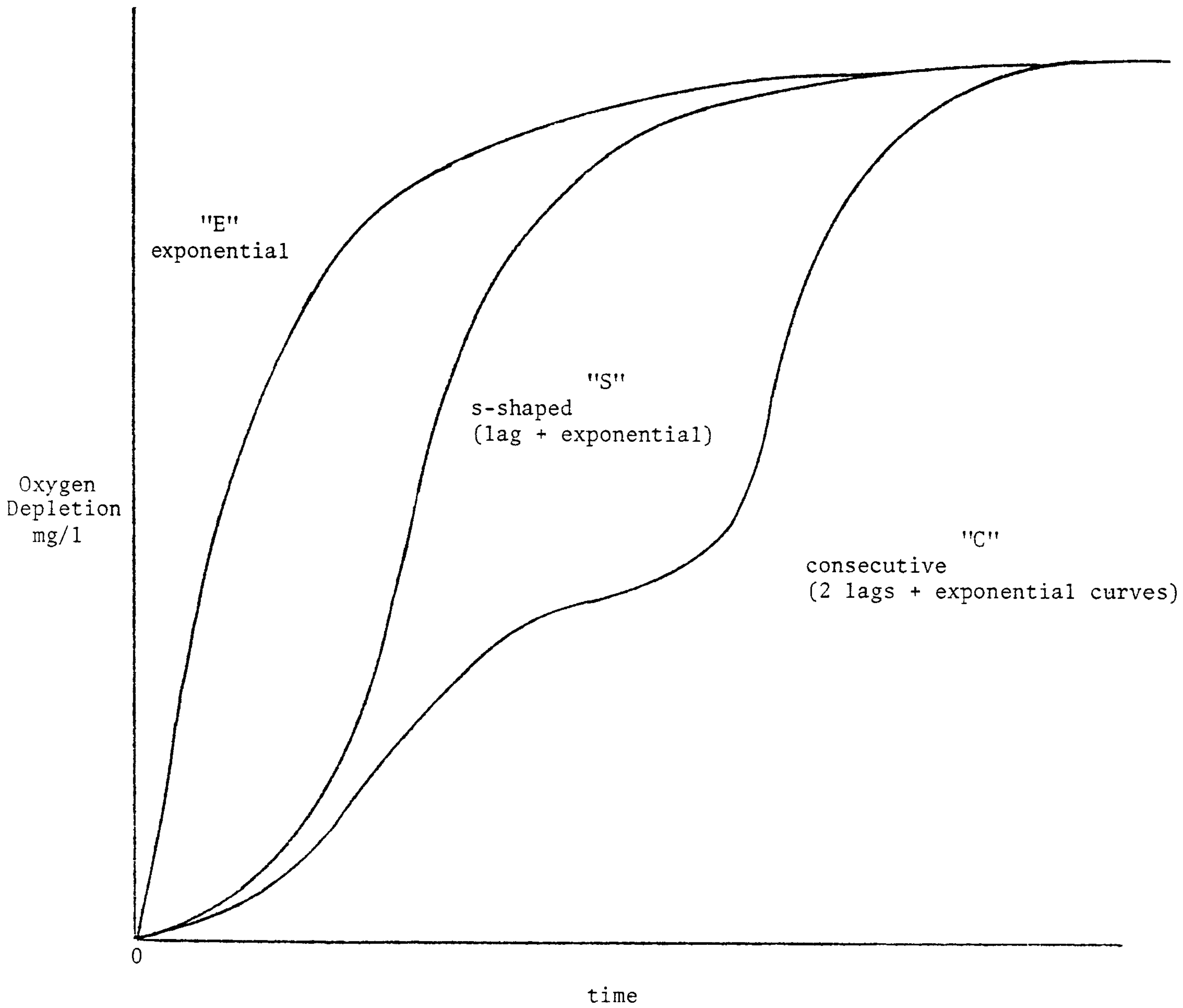
The average was limited to Hains Point to Fort Washington stations, because these stations represented the primary area associated with nitrification and the kinetics were limited to "E" Kinetics.

k_{10}: n = 25
$\bar{y}$ = .059
s.d. = .023

k_e = .14

r: n = 25
$\bar{y}$ = .91
r = .09

Figure #17 NOD Depletion Curves



pattern was observed in which exponential growth occurred after a lag phase in each of two distinct processes. This may involve the separation of $NH_4^+ \longrightarrow NO_2^-$ and $NO_2^- \longrightarrow NO_3^-$ by a lag stage. In the majority of the "exceptional" NOD stations an S-shaped pattern was observed with a lag time probably occurring for the Nitrosomonas conversion of NH_4^+ to NO_2^-. Nitrosomonas is considered the weak link in nitrification. All samples from the peak algal bloom period displayed a lag time with a resultant poor correlation coefficient in Thomas Plots. This suggests that the action of heterotrophic bacteria was necessary to liberate the required ammonia.

A consequence of the lag-free first order NOD kinetics observed for the majority of Potomac river samples is that the BOD_5 contains a significant NOD component. The average NOD_5/BOD_5 observed during the study (Table #7) was 0.33 (n=56).

TABLE # 7 NOD_5/BOD_5 and NOD_{20}/BOD_{20}

DATE - STA	NOD_5	$TBOD_5$	$NOD_5/TBOD_5$	NOD_{20}	$TBOD_{20}$	$NOD_{20}/TBOD_{20}$
July 20 - P8	0.2	3.2	.063	2.2	7.2	.306
1	0.4	3.4	.118	2.3	8.3	.278
3	1.4	6.6	.212	4.4	12.6	.349
4	2.2	4.8	.458	6.2	12.1	.512
5	4.6	9.0	.511	11.0	18.6	.591
6	4.6	9.9	.465	11.1	20.8	.534
7	0.8	5.0	.160	4.0	11.9	.336
8-A	1.2	5.2	.231	3.6	9.8	.367
10	0.7	4.5	.156	3.0	9.2	.327
11	1.4	5.2	.270	2.3	9.5	.242
July 27 - P8	---	---	---	1.4	5.4	.259
1	1.0	2.8	.357	1.5	5.0	.30
3	1.1	4.1	.268	2.6	7.7	.337
4	3.1	5.4	.574	5.3	9.4	.564
5	2.8	5.8	.483	5.6	10.7	.523
6	4.6	8.6	.535	6.8	14.9	.456
7	---	---	---	5.5	14.4	.382
8-A	1.6	4.7	.340	6.8	10.2	.666
10	1.4	4.4	.318	2.4	7.5	.32
11	1.7	3.6	.472	3.6	8.2	.439
			$n = 56$ $\bar{y} = .33$ $s = .18$			$n = 58$ $\bar{y} = .38$ $s = .11$

TABLE # 7 (con't) NOD_5/BOD_5 and NOD_{20}/BOD_{20}

DATE - STA	NOD_5	$TBOD_5$	$NOD_5/TBOD_5$	NOD_{20}	$TBOD_{20}$	$NOD_{20}/TBOD_{20}$
Aug. 3 - P8	---	---	---			
1	0.9	3.2	.281	1.4	5.5	.254
3	5.6	8.6	.651	7.3	12.4	.589
4	3.7	7.4	.500	4.8	11.4	.421
5	3.1	6.3	.492	5.0	10.2	.490
6	0.9	4.4	.204	3.3	8.6	.384
7	1.6	5.2	.308	4.4	10.9	.404
8-A	1.3	5.2	.250	4.0	11.8	.339
10	1.1	4.3	.256	3.8	10.2	.372
11	0.3	3.2	.094	1.8	8.0	.225
Aug. 24 - P8	0.9	4.0	.225	3.0	8.8	.341
1	0.4	3.0	.133	2.7	7.0	.386
3	2.9	5.1	.569	4.0	8.2	.488
4	3.4	7.0	.486	4.4	10.1	.436
5	1.8	7.0	.257	3.4	12.0	.283
6	2.1	6.4	.328	4.1	12.1	.339
7	0.9	5.5	.164	3.5	12.9	.271
8-A	0.4	8.0	.050	6.6	22.0	.300
10	0.0	6.6	0	6.8	24.1	.282
11	0.5	3.3	.152	4.2	13.2	.318
Aug. 31 - P8	0.7	2.8	.250	1.6	5.4	.296
1	0.9	3.3	.273	1.2	5.5	.218
3	6.0	9.2	.652	7.1	12.8	.555
4	4.7	8.5	.553	4.7	11.2	.420

TABLE # 7 (con't) NOD_5/BOD_5 and NOD_{20}/BOD_{20}

DATE - STA	NOD_5	$TBOD_5$	$NOD_5/TBOD_5$	NOD_{20}	$TBOD_{20}$	$NOD_{20}/TBOD_{20}$
Aug. 31 - 5 (con't)	3.9	7.6	.513	5.1	11.8	.432
6	2.8	8.0	.350	4.9	12.1	.405
7	3.7	8.8	.420	4.3	13.5	.318
8-A	4.5	9.7	.464	5.2	16.3	.319
10	2.6	8.9	.292	4.9	16.8	.292
11	1.7	3.3	.515	5.6	14.3	.392
Sept. 8 - P8	0.0	2.0	0	2.0	6.5	.308
1	0.1	2.7	.037	2.2	6.7	.328
3	2.8	5.3	.528	4.5	9.5	.474
4	4.6	9.4	.489	8.9	16.3	.546
5	7.0	11.8	.593	11.0	19.8	.556
6	---	---		---	---	
7	2.0	4.6	.435	3.6	8.1	.444
8-A	1.8	5.0	.360	3.0	9.1	.330
10	1.0	4.9	.204	2.5	9.8	.255
11	0.5	3.6	.139	3.0	9.0	.333

V. Oxygen Demand in the Potomac STP Effluent Samples

A. CBOD

The CBOD kinetics observed for the sewage treatment plant effluents were first order with an average $k_e = 0.17$ (n=19, s=0.02) and a average correlation coefficient of 0.86 (Table #8).

B. NOD

The NOD kinetics observed for the sewage treatment plant effluents were all characterized by a lag period which generally lasted for the first 10 to 15 days of incubation. The NOD expressed within five days, though relatively small compared to the NOD expressed after 10 to 12 days was significant and is included in Table #12. The average (n=30) NOD_5/BOD_5 value was 0.26 with considerable noise in the data, s=0.21. This relationship corresponded to an average $CBOD_5/BOD_5$ ratio of 0.74. The observed carbonaceous kinetics of $k_e = 0.17$ dictated a CBOD ultimate to $CBOD_5$ ratio of 1.75 and together with the observed ratio suggests:

$$CBOD_{(ultimate)} = BOD_5 \times 1.30$$

The relation CBOD ultimate = $BOD_5 \times 1.45$ is based upon the classical kinetics, k_e=.234[5] associated with sewage effluents and assumes an insignificant nitrification contribution. However, the factor 1.45 is not unsatisfactory for the Potomac STP effluents since it predicts $CBOD_{ultimate}$ values not significantly different from those predicted by the 1.30 factor. An STP effluent with a BOD_5 of 30.0 mg/1 would yield $CBOD_{ultimate}$ values of 39.0 mg/1 based upon the 1.3 factor and 43.5 mg/1 based upon the 1.45 factor. This is within the error associated with the BOD test[2] and provides a conservative estimate of the carbonaceous oxygen demand.

TABLE # 8 CBOD - STP

DATE - STA	Name	k_{10}	L_0	r	
July 20 - S1	Piscataway	.105	5.66	.997	
S2	Arlington	.075	10.09	.998	
S3	Blue Plains	.076 *	26.40	.844	1 lag phase
S4	Alexandria	.061	108.17	.997	
S5	Westgate	.074	21.68	.991	
S6	Hunting Creek	.069	22.79	.996	
S7	Dogue Creek	.050	16.95	.983	
S8	Pohick Creek	.055	34.16	.979	
Aug. 24 - S1	Piscataway	--	--	--	
S2	Arlington	.101	20.21	.998	
S3	Blue Plains	.072	44.04	.992	
S4	Alexandria	.092	84.27	.992	
S5	Westgate	.012 *	58.17	.257	2 lag phases
S6	Hunting Creek	.064	22.43	.998	
S7	Dogue Creek	.080	21.68	.997	
S8	Pohick Creek	.037 *	22.7	.621	2 lag phases
Aug. 31 - S1	Piscataway	--	--	--	
S2	Arlington	.012*	9.97	.588}	linear r=.991 m=.370 b=-.231
S3	Blue Plains	.101	32.52	.997	
S4	Alexandria	.101	57.59	.997	
S5	Westgate	--	--	--	
S6	Hunting Creek	--	--	--	
S7	Dogue Creek	.063	9.97	.976	
S8	Pohick Creek	.076	16.04	.997	

TABLE # 8 (con't) CBOD - STP

DATE - STA	Name	k_{10}	L_0	r	
Sept. 8 - S1	Piscataway	.009 *	29.30	.019	1 lag phase
S2	Arlington	--	--	--	
S3	Blue Plains	--	--	--	
S4	Alexandria	.069	94.97	.985	
S5	Westgate	.047	28.59	.995	
S6	Hunting Creek	.053	24.94	.989	
S7	Dogue Creek	.034*	20.49	.799	2 lags
S8	Pohick Creek	.007*	89.88	.469}	linear r=.991 m=1.294 b=.824

k:
n=19
$\bar{k}_{10}$=.074 $\bar{k}_e$=.017
s=.020

r:
n=26
$\bar{r}$=.86
s=.26

The Thomas correlation coefficients for NOD are listed in Table #9. The negative correlation consistently observed resulted from the lag in NOD. The oxygen depletion plots (figures 18, 19 & 20) were restricted to "S-shaped" and "consecutive S-shaped" patterns.

The fraction of the potential NOD, TKN-N x 4.57, expressed after 20 days is included in Table #10. The low recovery is related to the long lag phase observed for the NOD. Since the receiving waters have lag-free, first order kinetics, it is likely that the consistent NOD lag phase observed in STP samples is artifical and is perhaps due to the lack of nitrifying bacteria.

C. Loading Characteristics

The average flows and loadings based on: $CBOD_{20}$; TKN-N x 4.57 (NOD) and BOD_5 are presented in Table #11. The ratio of NOD_{20} to BOD_{20} for the STP effluents is compiled in Table #12 with an average value of 0.69 (n=27; s=0.11). The effluent loadings were therefore predominantly NOD, and as pointed out previously, the river samples were dominated by the CBOD. The predominant nitrogen form, in the STP effluents, (nearly to the exclusion of all other oxidation states) was ammonium (Table #13). This suggested that a portion of the discharged ammonium was being lost from the system, since nitrification would be expected to be very efficient for ammonia. A mechanism for this loss may be sorption of ammonia onto clays and organic colloids[22] in sediments and loss to the bottom by sedimentation. On the bottom denitrification would be expected to predominate[23].

TABLE # 9 (con't) NOD - STP

DATE - STA	Name	k_{10}	L_0	r	Curve Type (see fig.20)
July 20 - S1	Piscataway	-.005	-77.76	-.098	1 lag stage
S2	Arlington	-.0464	-5.68	-.758	
S3	Blue Plains	-.089	-1.85	-.743	1 lag stage
S4	Alexandria	-.024	-30.13	-.428	
S5	Westgate	-.034	-5.240	-.627	2 lag stages
S6	Hunting Creek	-.064	-3.35	-.811	
S7	Dogue Creek	-.014	-25.8	-.220	2 lag stages
S8	Pohick Creek	-.063	-2.59	-.912	
Aug. 24 - S1	Piscataway	-.025	-10.70	-.437	
S2	Arlington	-.089	-.89	-.927	1 lag stage
S3	Blue Plains	-.098	-.606	-.825	
S4	Alexandria	-.098	-.739	-.863	2 lag stages
S5	Westgate	-.076	-1.43	-.986	
S6	Hunting Creek	-.050	-6.61	-.895	2 lag stages
S7	Dogue Creek	-.082	-.989	-.797	
S8	Pohick Creek	-.066	-2.09	-.894	1 lag stage
Aug. 31 - S1	Piscataway	---	---	---	
S2	Arlington	---	---	---	
S3	Blue Plains	-.004	-176.6	-.083	2 lag stages
S4	Alexandria	-.063	-3.98	-.730	
S5	Westgate	-.051	-3.91	-.547	1 lag stage
S6	Hunting Creek	-.012	-4.46	-.1058	
S7	Dogue Creek	.008	109.17	.117	2 lag stages
S8	Pohick Creek	-.011	-81.8	-.388	

TABLE # 9 (con't) NOD - STP

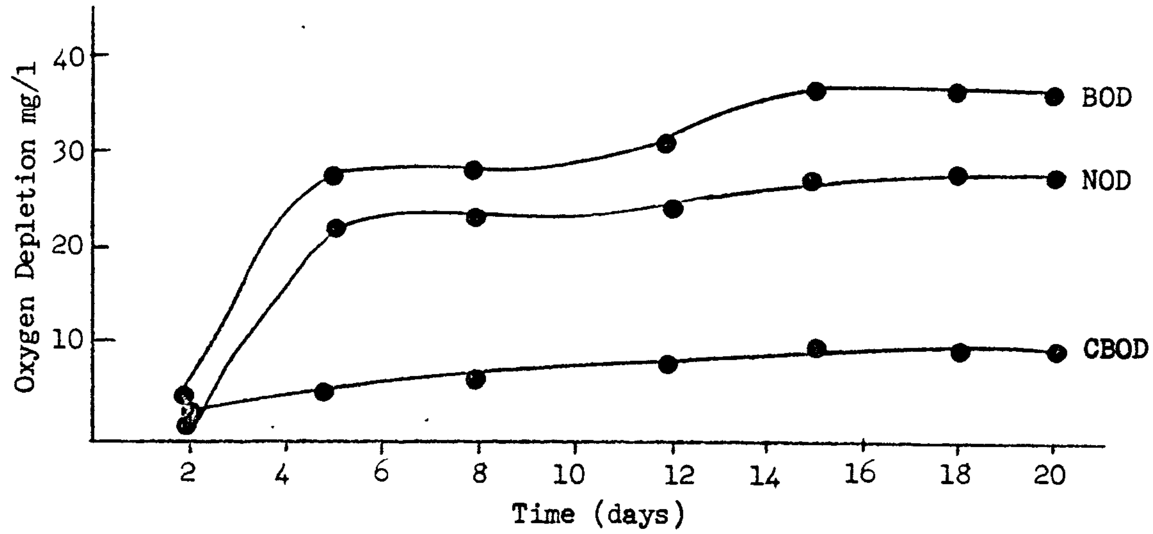
DATE - STA	Name	k_{10}	L_0	r	Curve Type (see fig.20)
Sept. 8 - S1	Piscataway	-.021	-24.59	-.526	
S2	Arlington	---	---	---	
S3	Blue Plains	---	---	---	
S4	Alexandria	-.044	-14.30	-.899	2 lag stages
S5	Westgate	-.026	-13.44	-.406	
S6	Hunting Creek	-.027	-17.4	-.591	2 lag stages
S7	Dogue Creek	-.074	-2.38	-.689	
S8	Pohick Creek	-.057	-6.89	-.897	2 lag stages

Figure #18

Oxygen Depletion Curves

Aug. 31, 1977

Dogue STP S-7



Sept. 8, 1977

Piscataway STP S-1

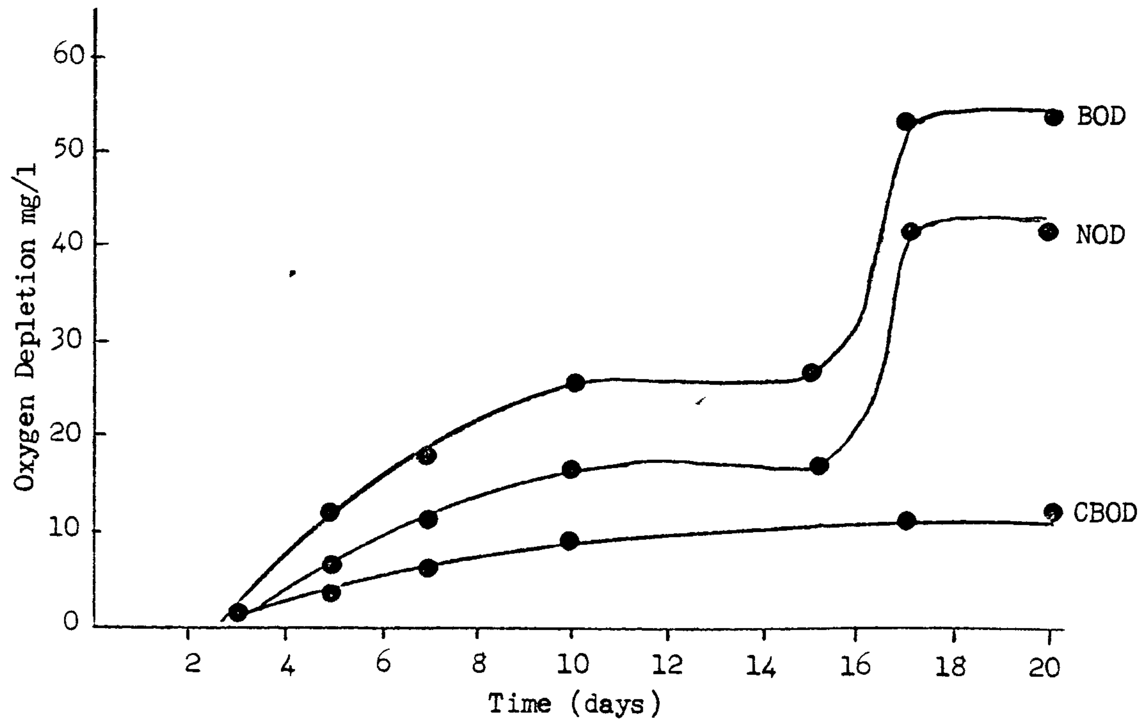


Figure #19 Oxygen Depletion Curves

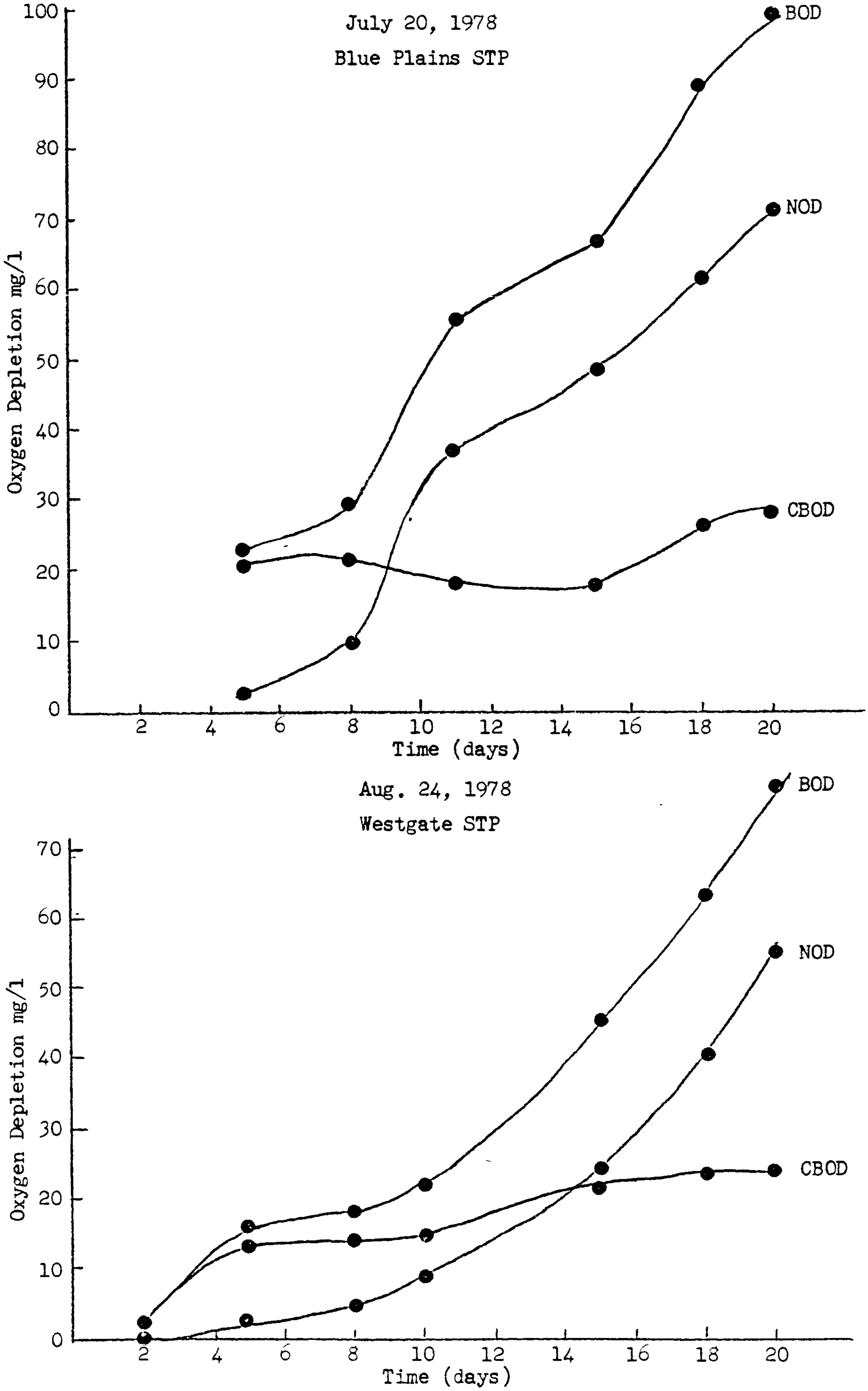
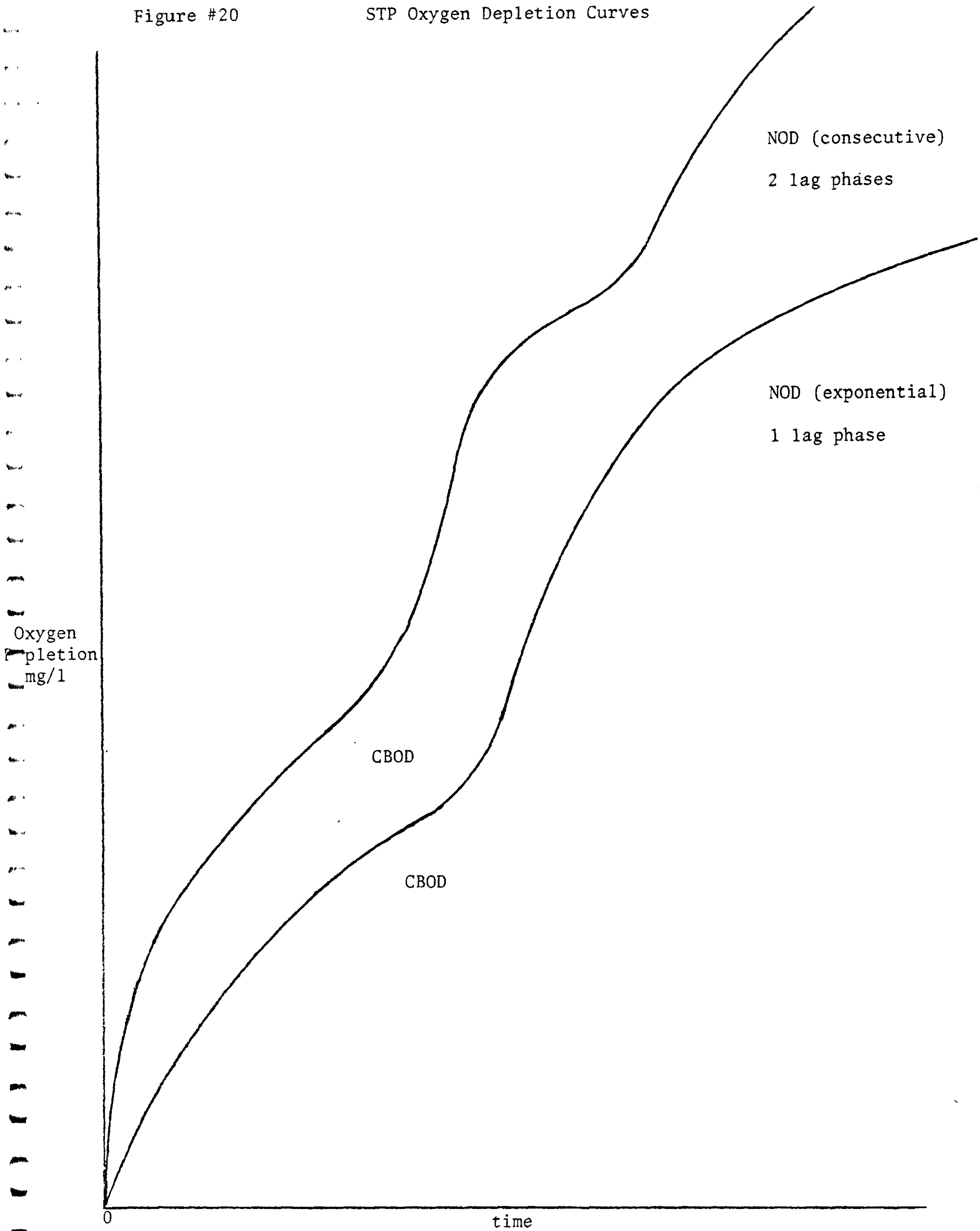


Figure #20 STP Oxygen Depletion Curves



TABLE# 10 Summary Sheet of % ($NOD^{*}_{20}/NOD^{*}_{ultimate}$) for STP's

Station	7/20	8/24	8/31	9/8	ave. $\bar{y}$		std. dev. s
S1-Piscataway	.747	.85	---	.92	.84	±	.09
S2-Arlington	.549	.56	.52	---	.54	±	.02
S3-Blue Plains	.873	.78	.57	---	.74	±	.16
S4-Alexandria	.961	.82	.68	1.06	.88	±	.17
S5-Westgate	.24	.61	---	.40	.42	±	.19
S6-Hunting Creek	.469	.55	---	.32	.45	±	.12
S7-Dogue Creek	.214	.41	.32	.42	.34	±	.10
S8-Pohick Creek	.417	.62	.53	.66	.56	±	.11

* NOD_{20} = NOD determined with the inhibitor

* $NOD_{ultimate}$ = TKN-N x 4.57

TABLE # 11 STP Loadings of $CBOD_{20}$, NOD Ultimate, and BOD_5

DATE - NAME	Flow (MGD)	20-day CBOD (mg/1)	Loading (1b/day)	TKNx4.57= NOD (mg/1)	Loading (1b/day)	BOD_5 Loading (1b/day)
July 20-Piscataway STP	12.48	4.8	499.9	24.05	2,504.7	749.8
Arlington STP	21.00	9.1	1,594.8	85.14	14,920.6	2,102.9
Blue Plains STP	280.00	27.6	64,491.4	81.78	191,090.7	53,274.9
Alexandria STP	19.40	99.0	16,027.7	98.61	15,964.6	11,462.0
Westgate STP	11.63	19.2	1,863.4	95.73	9,291.0	1,630.5
Hunting Creek STP	3.90	20.4	663.9	110.64	3,600.9	507.7
Dogue Creek STP	2.28	15.0	285.4	157.30	2,992.9	285.4
Pohick Creek STP	14.26	31.2	3,712.8	139.50	16,600.8	2,499.0
July 27-Piscataway STP	16.00	-	-	39.15	5,227.4	881.2
Arlington STP	19.90	-	-	61.67	10,241.5	1,096.0
Blue Plains STP	251.00	-	-	66.10	138,455.3	40,216.2
Alexandria STP	19.73	-	-	81.98	13,498.0	4,346.7
Westgate STP	11.51	-	-	77.55	7,448.9	864.5
Hunting Creek STP	3.75	-	-	84.57	2,646.6	187.8
Dogue Creek STP	2.28	-	-	73.49	1,398.3	79.9
Pohick Creek STP	13.79	-	-	97.86	11,261.7	1,726.2
Aug. 3-Piscataway STP	7.50	-	-	19.63	1,228.6	262.9
Arlington STP	20.20	-	-	73.20	12,339.5	606.8
Blue Plains STP	261.00	-	-	65.43	142,512.1	58,807.2
Alexandria STP	19.09	-	-	98.56	15,701.5	7,073.2
Westgate STP	11.15	-	-	83.01	7,724.0	558.3
Hunting Creek STP	4.17	-	-	92.42	3,216.2	229.7
Dogue Creek STP	2.16	-	-	90.38	1,629.1	54.1
Pohick Creek STP	14.18	-	-	110.42	13,066.5	994.0

TABLE # 11 (con't) STP Loadings of $CBOD_{20}$, NOD Ultimate, and BOD_5

DATE - NAME	Flow (MGD)	20-day CBOD (mg/l)	Loading (lb/day)	TKNx4.57= NOD (mg/l)	Loading (lb/day)	BOD_5 Loading (lb/day)
Aug. 24-Piscataway STP	10.99	0	0	22.52	2,065.3	27.5
Arlington STP	19.30	17.4	2,802.5	97.31	15,672.6	2,415.9
Blue Plains STP	282.00	39.6	93,192.0	76.71	180,520.9	57,890.9
Alexandria STP	19.24	75.6	12,138.4	99.99	16,054.2	8,959.1
Westgate STP	10.43	23.4	2,036.7	90.44	7,871.7	1,357.8
Hunting Creek STP	4.04	20.0	674.3	94.64	3,190.7	505.7
Dogue Cr-ek STP	2.09	19.5	340.1	95.41	1,664.1	230.2
Pohick Creek STP	13.70	16.2	1,852.1	48.46	5,540.3	1,714.9
Aug. 31-Piscataway STP	12.13	--		20.84	2,109.5	0
Arlington STP	20.80	7.2	1,249.7	55.20	9,581.4	208.3
Blue Plains STP	297.00	28.2	69,892.7	67.64	167,643.3	69,892.7
Alexandria STP	20.18	49.8	8,386.4	85.92	14,469.1	6,971.8
Westgate STP	10.59	15.6*	1,378.6	77.51	6,849.8	1,537.7
Hunting Creek STP	4.09	14.4*	491.5	87.74	2,994.7	512.0
Dogue Creek STP	2.15	9.0	161.5	79.34	1,423.5	495.2
Pohick Creek STP	13.91	14.4	1,671.5	100.90	11,712.4	2,577.0
Sept. 8-Piscataway STP	10.95	12.0	1,096.6	33.36	3,048.4	1,069.1
Arlington STP	20.80	15.6*	2,707.8	37.07	6,434.6	2,707.8
Blue Plains STP	313.00	132.0*	344,781.9	77.44	202,275.9	344,781.9
Alexandria STP	19.44	84.6	13,724.6	82.38	13,364.5	11,193.6
Westgate STP	10.44	25.4	2,212.9	102.15	8,899.7	1,672.7
Hunting Creek STP	4.00	21.0	701.0	107.92	3,602.4	560.8
Dogue Creek STP	2.63	18.0	395.1	103.80	2,278.2	322.6
Pohick Creek STP	14.24	27.9	3,315.5	115.74	13,754.0	1,853.8

* 18-day BOD

$$\text{Loading (lb/day)} = \frac{\text{BOD (mg/l)} \times \text{Flow (MGD)} \times 2000}{239.66}$$

TABLE # 12 Proportion of Total STP Demand Expressed as NOD

DATE - STA	NOD_5	BOD_5	NOD_5/BOD_5	NOD_{20}	BOD_{20}	NOD_{20}/BOD_{20}
July 20 - S1	3.0	7.2	.42	18.0	22.8	.789
S2	6.0	12.0	.50	46.7	55.8	.837
S3	1.8	22.8	.079	71.4	99.0	.721
S4	14.4	70.8	.20	94.8	193.8	.489
S5	3.6	16.8	.21	28.8	48.0	.600
S6	2.4	15.6	.15	51.9	72.3	.718
S7	7.2	15.0	.48	33.6	48.6	.691
S8	3.6	21.0	.17	58.2	89.4	.651
Aug. 24 - S1	0	0	-	19.2	19.2	1
S2	1.2	15.0	.080	54.6	72.0	.758
S3	0.6	24.6	.024	60.0	99.6	.602
S4	2.4	55.8	.043	82.2	157.8	.521
S5	1.8	15.6	.12	55.8	79.2	.704
S6	3.6	15.0	.24	52.2	72.2	.723
S7	0.6	13.2	.045	39.0	58.5	.667
S8	1.8	15.0	.12	30.0	46.2	.649
Aug. 31 - S1	-	-	-			
S2	0	1.2	0	31.2	38.4	.812
S3	6.0	28.2	.21	38.4	66.6	.576
S4	1.8	41.4	.044	58.8	108.6	.541
S5	2.4	17.4	.14	-	-	
S6	0.6	15.0	.040	-	-	
S7	22.8	27.6	.83	27.6	36.6	.754
S8	12.4	22.2	.56	55.8	70.2	.795

TABLE # 12 (con't) Proportion of Total STP Demand Expressed as NOD

DATE - STA	NOD_5	BOD_5	NOD_5/BOD_5	NOD_{20}	BOD_{20}	NOD_{20}/BOD_{20}
Sept. 8 - S1	6.3	11.7	.54	42.0	54.0	.778
S2	10.2	15.6	.65	-	-	
S3	42.0	132.0	.32	-	-	
S4	11.4	69.0	.17	87.6	172.2	.509
S5	7.2	19.2	.38	41.2	66.6	.619
S6	4.8	16.8	.29	34.8	55.8	.624
S7	6.3	14.7	.43	44.0	62.4	.705
S8	6.6	15.6	.42	76.5	104.4	.733
			n=30 $\bar{x}$=.26 s=.21			n=27 $\bar{x}$=.69 s=.11

TABLE # 13 NO_2-N Concentration and the Resulting NOD Error

DATE/STA	NO_3-N (mg/l)	NO_2-N (mg/l)	1.14x NO_2-N	NH_3-N (mg/l)	TKN-N (mg/l)	4.57x TKN-N	% Error	STA	RMI
July 20									
P-8	N.D.	N.D.	N.D.	.087	.741	3.4	N.D.	P-8	0.0
P-4	N.D.	N.D.	N.D.	N.D.	.621	2.8	N.D.	P-4	1.9
1	N.D.	N.D.	N.D.	N.D.	.705	3.2	N.D.	1	3.4
1-A	N.D.	N.D.	N.D.	N.D.	.632	2.9	N.D.	1-A	4.9
2	N.D.	N.D.	N.D.	N.D.	.632	2.9	N.D.	2	5.9
3	.174	.107	.1	.234	.821	3.8	2.6	3	7.6
4	.160	.155	.2	1.094	2.052	9.4	2.1	4	10.0
5	.162	.222	.2	1.240	2.495	11.4	1.8	5	12.1
5A	.360	.558	.6	1.02	2.429	11.1	5.4	5A	13.6
6	.535	.606	.7	.800	2.200	10.1	6.9	6	15.2
7	.892	.328	.4	.291	1.358	6.2	6.4	7	18.4
8	1.243	.126	.1	.186	1.179	5.4	1.8	8	22.3
8A	1.060	.078	.1	.134	1.074	4.9	2.0	8A	24.3
9	.893	.055	.1	.071	.842	3.8	2.6	9	26.9
10	.834	.059	.1	.095	.853	3.9	2.6	10	30.6
10B	.618	.063	.1	.092	.726	3.3	3.0	10B	34.0
11	.382	N.D.	N.D.	.026	.621	2.8	N.D.	11	38.0
12	.164	N.D.	N.D.	N.D.	.600	2.7	N.D.	12	42.5
13	.080	N.D.	N.D.	N.D.	.453	2.1	N.D.	13	45.8
14	.144	N.D.	N.D.	.128	.474	2.2	N.D.	14	52.4
15	.073	N.D.	N.D.	.060	.863	3.9	N.D.	15	58.6
15A	.046	N.D.	N.D.	.094	.442	2.0	N.D.	15A	62.8
16	N.D.	N.D.	N.D.	.040	.621	2.8	N.D.	16	67.4
S1	5.755	.315	.4	3.09	5.263	24.1	1.6	S1	STP
S2	2.189	.241	.3	18.4	18.631	85.1	.4	S2	STP

TABLE # 13 (con't) NO_2-N Concentration and the Resulting NOD Error

DATE/STA	NO_3-N (mg/l)	NO_2-N (mg/l)	1.14x NO_2-N	NH_3-N (mg/l)	TKN-N (mg/l)	4.57x TKN-N	% Error	STA	RMI
July 20									
S3	N.D.	N.D.	N.D.	16.4	17.894	81.8	N.D.	S3	STP
S4	N.D.	N.D.	N.D.	17.0	21.578	98.6	N.D.	S4	STP
S5	N.D.	N.D.	N.D.	36.6	20.941	95.7	N.D.	S5	STP
S6	1.557	.213	.2	23.1	24.210	110.6	.2	S6	STP
S7	.734	.236	.3	29.4	34.420	157.3	.2	S7	STP
S8	.048	.044	.1	22.6	30.525	139.5	.1	S8	STP

N.D. $< .04$ N.D. $< .04$ N.D. $< .02$

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Appendix

A. N-Serve/NOD Determinations

The inhibitor incorporated was formula 2533 Nitrification Inhibitor, a product of the Hach Chemical Company. The product consists of 2-chloro-6(trichloromethyl) pyridine known as TCMP or N-Serve. This compound is plated on a simple inorganic salt which serves as a carrier and is soluble in water. The Dow Chemical Company, Midland, Michigan, markets this chemical under the name N-Serve as a fertilizer additive. Studies[23,24,25,26] using N-Serve suggest that it acts as a "biostat" at moderate concentrations to delay nitrification and aids the retention of ammonia or urea fertilizers on crops by retarding the conversion to the more highly leachable NO_3^-. Ideally TCMP is slowly biodegraded to 6-chloropicolinic acid which leaves the fields in their original state, with no further inhibition to nitrification. This allows long term (20-30 day) NOD assays without significant inhibitor contribution to the carbonaceous demand.[21,27] Extensive studies[28] were performed on the toxicity of this material, because of concern for the environment. These have revealed it to be very selective and effective at stopping nitrification at 10 ppm.[21,27]

Although the mechanism of its action is still unclear, it is restricted to Nitrosomonas. This selectivity is an advantage in that it stops the process of nitrification at ammonia with little or no effect on urea hydrolysis,[29] assuring an adequate nitrogen source for the heterotrophic bacteria contributing to the CBOD. The disadvantage of this selectivity is that Nitrobacter are not inhibited and NO_2^- will be oxidized to NO_3^-. This limitation generally represents a small error since NO_2^- is generally much smaller than TKN in river water and the demand associated with the NO_2 initially present is $\frac{1.14}{4.57}$ or one-quarter that associated with the TKN initially in the sample.

The Potomac intensive survey did not include the separate determination of NO_2 and NO_3, but incorporated cadmium reduction technique whereby the sum concentration of NO_2 plue NO_3 was determined. The initial run, however, was assayed for NO_2 separately to determine the significance of the potential error associated with TCMP. This data is compiled in Table #13 with a maximum potential error of 5 to 7% associated with the NOD determination of 3 out of a total of 23 river stations and 9 waste treatment effluents. This error was not considered significant enough to justify the added time and cost involved in the analysis of NO_2 throughout the course of this study.

B. Alternative Methods

Several other alternate approaches to determining NOD were considered. In situ tests, where a segment of water is followed and assayed for D.O. and states of nitrogen would give actual "river rates" for NOD and CBOD. However; the flows of a large, complex, tidal estuary are not adequately defined. Even if the segment of water could be followed it is altered by diffusion and by the input of effluents, resulting in a faulty estimate of the NOD rate.

Laboratory studies involving the incubation of samples with analysis of sub-samples at timed intervals for all nitrogen states, coupled with the determination of NOD based upon the stoichiometric relation between oxygen utilization and nitrogen oxidation is a second method for NOD determinations.

A second approach to laboratory studies involves only D.O. analyses, not the extensive laboratory committment associated with frequent N-series determination. One such method involves killing all of the bacteria present by pasteurization, chlorination, or acidification and reseeding with populations containing few nitrifyers. However, these methods involve the disadvantages associated with extensive sample modification. A second D.O. method involves killing or inhibiting the nitrifyers by addition of: methylene blue; thiourea; allylthiourea ATU; and TCMP. Methylene blue interferes with Winkler D.O. determinations as does thiourea. Further, only Temp has been found effective for long term experiments, because the others were either degraded thus contributing to the CBOD or Nitrosomonas quickly acclimated to their effect and nitrification began.[21]

TABLE # 14

C. Study Data

Potomac River Long-Term BOD Survey Data-Summer 1977

Date: 7/20/77

STA #		Days of Incubation 5	8	11	15	18	20
P-8	T*	3.2	4.2	5.6	6.8	7.0	7.2
	C*	3.0	4.0	4.3	4.6	4.8	5.0
	N*	0.2	.2	1.3	2.2	2.2	2.2
P-4	T	3.6					
1	T	3.4	4.9	6.1	7.4	8.0	8.3
	C	3.0	4.0	4.6	5.2	5.8	6.0
	N	0.4	0.9	1.5	2.2	2.2	2.3
1-A	T	3.7					
2	T	4.0					
3	T	6.6	7.7	8.3	10.8	11.2	12.6
	C	5.2	5.2	5.2	7.6	8.0	8.2
	N	1.4	2.5	3.1	3.2	3.2	4.4
4	T	4.8	9.7	11.0	11.7	12.0	12.1
	C	2.6	4.4	5.1	5.5	.58	5.9
	N	2.2	5.3	5.9	6.2	6.2	6.2
5	T	9.0	12.8	14.1	17.1	17.5	18.6
	C	4.4	5.5	6.5	7.0	7.4	7.6
	N	4.6	7.3	7.6	10.1	10.1	11.0
5-A	T	8.1					
6	T	9.9	11.4	11.8	17.0	19.3	20.8
	C	5.3	5.0	5.0	8.6	9.4	9.7
	N	4.6	6.4	6.8	8.4	9.9	11.1
7	T	5.0	8.0	9.8	11.1	11.5	11.9
	C	4.2	5.5	6.0	7.3	7.7	7.9
	N	0.8	2.5	3.8	3.8	3.8	4.0
8	T	4.6					
8-A	T	5.2	7.3	8.1	9.0	9.2	9.8
	C	4.0	5.0	5.7	6.0	6.2	6.2
	N	1.2	2.3	2.4	3.0	3.0	3.6

*T - BOD (mg/1)
*C - CBOD (mg/1)
*N - NOD (mg/1)

TABLE # 14 (con't)

Date: 7/20/77

STA #		Days of Incubation 5	8	11	15	18	20
9	T	4.9					
10	T*	4.5	6.2	7.8	8.2	8.9	9.2
	C*	3.8	4.7	5.4	5.6	5.9	6.2
	N*	0.7	1.5	2.4	2.6	3.0	3.0
10-B	T	3.9					
11	T	5.2	6.1	7.1	8.2	9.3	9.5
	C	3.8	4.7	5.7	6.3	7.0	7.2
	N	1.4	1.4	1.4	1.9	2.3	2.3
12	T	4.6					
13	T	4.5					
14	T	2.5					
15	T	13.2					
15-A	T	4.0					
16	T	7.8					
S-1	T	7.2	18.0	20.4	22.8	22.8	22.8
	C	4.2	4.6	4.8	4.8	4.8	4.8
	N	3.0	13.4	15.6	18.0	18.0	18.0
S-2	T	12.0	13.8	16.0	33.0	54.7	55.8
	C	6.0	7.4	8.3	8.7	9.1	9.1
	N	6.0	6.4	7.8	24.3	45.6	46.7
S-3	T	22.8	28.6	55.4	66.4	89.1	99.0
	C	21.0	19.0	18.0	17.0	26.7	27.6
	N	1.8	9.6	37.4	49.4	62.4	71.4
S-4	T	70.8	88.0	102.3	117.6	153.6	193.8
	C	56.4	73.0	83.5	94.0	94.0	99.0
	N	14.4	15.0	18.8	23.6	59.6	94.8
S-5	T	16.8	18.0	25.2	26.2	39.0	48.0
	C	13.2	14.4	18.0	19.0	19.2	19.2
	N	3.6	3.6	7.2	7.2	19.8	28.8

*T - BOD (mg/1)
*C - CBOD (mg/1)
*N - NOD (mg/1)

Date: 7/20/77

STA #		Days of Incubation 5	8	11	15	18	20
S-6	T*	15.6	25.2	48.0	58.2	68.4	72.3
	C*	13.2	15.6	18.0	20.4	20.4	20.4
	N*	2.4	9.6	30.0	37.8	48.0	51.9
S-7	T	15.0	17.2	18.2	23.0	40.8	48.6
	C	7.8	10.0	11.0	14.0	14.4	15.0
	N	7.2	7.2	7.2	9.0	26.4	33.6
S-8	T	21.0	23.4	35.0	57.6	61.2	89.4
	C	17.4	19.8	26.0	27.0	29.4	31.2
	N	3.6	4.2	9.0	30.6	31.8	58.2

Date: 7/27/77

STA #		2	5	8	11	15	18	20
P-8	T	.3	1.5	1.1	2.2	4.5	5.1	5.4
	C	--	--	1.1	2.2	3.2	3.8	4.0
	N	--	--	0	0	1.3	1.3	1.4
P-4	T	.7	2.2					
1	T	1.0	2.8	3.5	3.7	4.2	5.0	5.0
	C	1.0	1.8	2.5	2.7	3.2	3.5	3.5
	N	0.0	1.0	1.0	1.0	1.0	1.5	1.5
1-A	T	1.0	2.4					
2	T	1.2	2.2					
3	T	2.1	4.1	5.6	6.6	7.3	7.7	7.7
	C	1.6	3.0	3.8	4.4	4.8	5.1	5.1
	N	0.5	1.1	1.8	2.2	2.5	2.6	2.6
4	T	2.4	5.4	6.8	7.8	8.8	9.4	9.4
	C	1.0	2.3	3.2	3.5	3.8	4.1	4.1
	N	1.4	3.1	3.6	4.3	5.0	5.3	5.3
5	T	2.1	5.8	6.8	7.7	8.9	9.8	10.7
	C	1.5	3.0	3.8	--	4.7	4.9	5.1
	N	0.6	2.8	3.0	--	4.2	4.9	5.6
5-A	T	3.3	7.5					
6	T	3.9	8.6	10.5	12.2	13.6	14.6	14.9
	C	1.7	4.0	5.5	6.5	7.2	8.0	8.9
	N	2.2	4.6	5.0	5.7	6.4	6.6	6.8

*T - BOD (mg/1)
*C - CBOD (mg/1)
*N - NOD (mg/1)

TABLE # 14 (con't)

Date: 7/27/77

STA #		Days of Incubation 2	5	8	11	15	18	20
7	T*	3.6	.51	5.7	7.5	9.6	11.8	14.4
	C*	2.1	--	3.0	4.2	5.6	6.3	8.9
	N*	1.5	--	2.7	3.3	4.0	5.5	5.5
8	T	2.6	5.6					
8-A	T	0.8	4.7	7.6	8.7	9.0	9.8	10.2
	C	0.4	3.1	3.8	4.9	5.2	6.0	6.4
	N	0.4	1.6	3.8	3.8	3.8	3.8	3.8
9	T	1.6	4.2					
10	T	1.5	4.4	5.0	6.0	6.1	6.4	7.5
	C	1.5	3.0	3.6	4.6	4.7	5.0	5.1
	N	0.0	1.4	1.4	1.4	1.4	1.4	2.4
10-B	T	1.5	3.7					
11	T	1.2	3.6	4.0	5.6	7.2	8.0	8.2
	C	.6	1.9	2.3	3.2	3.8	4.4	4.6
	N	.6	1.7	1.7	2.4	3.4	3.6	3.6
12	T	1.0	2.7					
13	T	0.7	2.2					
14	T	0.8	1.9					
15	T	1.2	3.4					
15-A	T	0.0	1.2					
16	T	1.1	2.6					
S-1	T	1.8	6.6	10.8	16.2	27.0	28.2	28.8
S-2	T	3.6	6.6	11.2	11.2	12.0	13.2	13.2
S-3	T	9.6	19.2	22.8	25.8	45.6	57.6	72.0
S-4	T	12.0	26.4	32.4	32.4	32.4	32.4	32.4
S-5	T	3.3	9.0	15.6	15.6	15.6	17.4	18.6

*T - BOD (mg/1)
*C - CBOD (mg/1)
*N - NOD (mg/1)

TABLE # 14 (con't)

Date: 7/27/77

STA #		Days of Incubation 2	5	8	11	15	18	20
S-6	T	5.4	6.0	12.0	12.0	13.2	18.0	22.8
S-7	T	2.4	4.2	12.0	12.0	12.6	14.4	16.8
S-8	T	7.8	15.0	21.6	21.6	22.2	26.4	28.8

Date: 8/03/77

STA #		2	5	8	11	15	18	20
P-8	T	1.3	1.7	1.7	1.7	1.7	2.2	2.4
P-4	T	1.4	2.4					
1	T*	2.2	3.2	4.4	4.6	4.9	5.3	5.5
	C*	1.3	2.3	3.3	3.5	3.6	3.9	4.1
	N*	0.9	0.9	1.1	1.1	1.3	1.4	1.4
1-A	T	2.6	4.2					
2	T	2.9	4.0					
3	T	3.2	8.6	9.4	10.4	11.9	12.4	12.4
	C	0.5	3.0	3.8	4.5	4.8	5.1	5.1
	N	2.7	5.6	5.6	5.9	7.1	7.3	7.3
4	T	4.1	7.4	8.5	9.4	10.4	10.9	11.4
	C	1.9	3.7	4.8	5.7	5.8	6.1	6.6
	N	2.2	3.7	3.7	3.7	4.6	4.8	4.8
5	T	4.2	6.3	7.5	8.3	10.0	10.0	10.2
	C	1.5	3.2	4.1	4.9	5.2	5.2	5.2
	N	2.7	3.1	3.4	3.4	4.8	4.8	5.0
5-A	T	3.8	6.4					
6	T	2.6	4.4	6.2	6.9	7.9	8.1	8.6
	C	2.0	3.5	4.6	5.0	5.3	5.3	5.3
	N	0.6	0.9	1.6	1.9	2.6	2.8	3.3
7	T	2.3	5.2	8.0	9.0	9.9	10.8	10.9
	C	1.5	3.6	5.0	5.5	5.9	6.2	6.5
	N	0.8	1.6	3.0	3.5	4.0	4.4	4.4

*T - BOD (mg/1)
*C - CBOD (mg/1)
*N - NOD (mg/1)

TABLE # 14 (con't)

Date: 8/03/77

STA #		Days of Incubation 2	5	8	11	15	18	20
8	T	2.9	5.3					
8-A	T*	3.0	5.2	7.4	8.8	10.6	11.1	11.8
	C*	2.2	3.9	5.4	6.3	6.8	7.1	7.8
	N*	0.8	1.3	2.0	2.5	3.8	4.0	4.0
9	T	3.2	5.4					
10	T	2.0	4.3	7.0	7.8	9.1	9.7	10.2
	C	1.6	3.2	4.5	5.3	5.6	6.0	6.4
	N	0.4	1.1	2.5	2.5	3.5	3.7	3.8
10-B	T	1.7	3.8					
11	T	1.8	3.2	4.8	5.9	6.6	7.2	8.0
	C	1.7	2.9	4.0	4.7	5.3	5.4	6.2
	N	0.1	0.3	0.8	1.2	1.3	1.8	1.8
12	T	1.6	2.9					
13	T	0.5	1.3					
14	T	1.2	1.3					
15	T	1.3	1.9					
15-A	T	1.0	0.8					
16	T	1.4	1.6					
S-1	T	4.2	4.2					
S-2	T	3.6	3.6					
S-3	T	18.6	27.0					
S-4	T	31.8	44.4					
S-5	T	6.0	6.0					
S-6	T	0.6	6.6					
S-7	T	3.0	3.0					
S-8	T	8.4	8.4					

*T - BOD (mg/1)
*C - CBOD (mg/1)
*N - NOD (mg/1)

TABLE # 14 (con't)

Date: 8/24/77

STA #		Days of Incubation 2	5	8	10	15	18	20
P-8	T*	2.0	4.0	4.8	5.8	7.0	8.0	8.8
	C*	1.6	3.1	3.6	4.4	5.0	5.4	5.8
	N*	0.4	0.9	1.2	1.4	2.0	2.6	3.0
P-4	T	1.3	2.9					
1	T	1.8	3.0	4.1	4.8	6.3	6.6	7.0
	C	1.6	2.6	3.3	3.8	4.0	4.2	4.3
	N	0.2	0.4	0.8	1.0	2.3	2.4	2.7
1-A	T	1.7	2.7					
2	T	1.5	2.5					
3	T	2.6	5.1	6.5	7.0	7.6	8.1	8.2
	C	1.4	2.2	2.9	3.4	3.6	4.1	4.2
	N	1.2	2.9	3.6	3.6	4.0	4.0	4.0
4	T	3.6	7.0	8.0	8.7	9.2	9.9	10.1
	C	2.0	3.6	4.2	4.8	5.3	5.6	5.7
	N	1.6	3.4	3.8	3.9	3.9	4.3	4.4
5	T	3.3	7.0	8.8	9.6	10.8	11.4	12.0
	C	2.6	5.2	6.0	6.8	7.9	8.3	8.6
	N	0.7	1.8	2.8	2.8	2.9	3.1	3.4
5-A	T	3.6	7.4					
6	T	3.4	6.4	8.1	9.1	10.6	11.6	12.1
	C	2.6	4.3	5.6	6.3	7.3	7.9	8.0
	N	0.8	2.1	2.5	2.8	3.3	3.7	4.1
7	T	3.1	5.5	9.2	9.6	11.4	12.4	12.9
	C	2.3	4.6	6.6	7.0	8.2	9.0	9.4
	N	0.8	0.9	2.6	2.6	3.2	3.4	3.5
8	T	1.5	5.0					
8-A	T	2.3	8.0	12.8	16.2	19.2	21.4	22.0
	C	2.3	7.6	10.2	11.4	13.3	15.1	15.4
	N	0	0.4	2.6	4.8	5.9	6.3	6.6
9	T	2.6	6.4					

*T - BOD (mg/l)
*C - CBOD (mg/l)
*N - NOD (mg/l)

TABLE # 14 (con't)

Date: 8/24/77

STA #		Days of Incubation 2	5	8	10	15	18	20
10	T*	3.0	6.6	13.6	17.3	20.9	23.1	24.1
	C*	3.0	6.6	12.2	14.1	15.7	16.8	17.3
	N*	0	0	1.4	3.2	5.2	6.3	6.8
10-B	T	1.8	3.0					
11	T	1.2	3.3	4.7	6.5	10.2	11.8	13.2
	C	1.2	2.8	3.8	5.6	7.7	8.6	9.0
	N	0	0.5	0.9	0.9	2.5	3.2	4.2
12	T	1.8	3.0					
13	T	0.9	1.6					
14	T	0.5	1.4					
15	T	0.8	1.0					
15-A	T	0.8	1.2					
16	T	1.1	1.3					
S-1	T	0	0	4.2	13.2	18.6	19.2	19.2
	C	0	0	0	0	0	0	0
	N	0	0	4.2	13.2	18.6	19.2	19.2
S-2	T	8.1	15.0	19.6	26.6	66.0	72.0	72.0
	C	8.1	13.8	16.0	17.0	17.4	17.4	17.4
	N	0	1.2	3.6	9.6	48.6	54.6	54.6
S-3	T	13.8	24.6	35.4	47.2	88.8	94.8	99.6
	C	13.8	24.0	29.4	34.0	39.6	39.6	39.6
	N	0	0.6	6.0	13.2	49.2	55.2	60.0
S-4	T	33.8	55.8	71.4	80.2	106.2	138.6	157.8
	C	33.6	53.4	61.2	70.0	72.6	74.4	75.6
	N	0.2	2.4	10.2	10.2	33.6	64.2	82.2
S-5	T	2.0	15.6	18.0	22.2	45.6	63.0	79.2
	C	2.0	13.8	13.8	13.8	22.2	22.8	23.4
	N	0	1.8	4.2	8.4	23.4	40.2	55.8
S-6	T	7.8	15.0	27.6	33.8	57.0	64.4	72.2
	C	6.0	11.4	15.0	17.0	19.2	20.0	20.0
	N	1.8	3.6	12.6	16.8	37.8	44.4	52.2

*T - BOD (mg/1)
*C - CBOD (mg/1)
*N - NOD (mg/1)

TABLE # 14 (con't)

Date: 8/24/77

STA #		Days of Incubation 2	5	8	10	15	18	20
S-7	T*	7.6	13.2	22.6	29.0	44.4	58.5	58.5
	C*	7.0	12.6	16.0	18.2	18.3	19.5	19.5
	N*	0.6	0.6	6.6	10.8	26.1	39.0	39.0
S-8	T	2.6	15.0	20.4	26.8	46.2	46.2	46.2
	C	2.0	13.2	13.2	16.0	16.2	16.2	16.2
	N	0.6	1.8	7.2	10.8	30.0	30.0	30.0

Date: 8/31/77

STA #		2	5	8	12	15	18	20
P-8	T	1.7	2.8	3.4	4.6	4.8	5.1	5.4
	C	1.0	2.1	2.6	3.2	3.4	3.7	3.8
	N	0.7	0.7	0.8	1.4	1.4	1.4	1.6
P-4	T	2.1	3.0					
1	T	1.2	3.3	3.8	4.6	4.9	4.9	5.5
	C	1.2	2.4	2.9	3.7	4.0	4.0	4.3
	N	0	0.9	0.9	0.9	0.9	0.9	1.2
1-A	T	2.7	3.8					
2	T	1.9	2.9					
3	T	2.4	9.2	10.5	11.4	11.8	12.2	12.8
	C	0.5	3.2	4.3	5.1	5.2	5.5	5.7
	N	1.9	6.0	6.2	6.3	6.6	6.7	7.1
4	T	4.7	8.5	9.6	10.3	10.5	10.8	11.2
	C	1.9	3.8	4.9	--	6.0	6.3	6.5
	N	2.8	4.7	4.7	--	4.5	4.5	4.7
5	T	3.8	7.6	8.8	10.1	10.8	11.7	11.8
	C	1.6	3.7	4.6	5.7	5.9	6.8	6.7
	N	2.2	3.9	4.2	4.4	4.9	4.9	5.1
5-A	T	3.8	6.7					
6	T	3.8	8.0	9.4	10.4	11.1	11.4	12.1
	C	3.0	5.2	6.3	6.9	7.2	7.2	7.2
	N	0.8	2.8	3.1	3.5	3.9	4.2	4.9

*T - BOD (mg/1)
*C - CBOD (mg/1)
*N - NOD (mg/1)

TABLE # 14 (con't)

Date: 8/31/77

STA #		Days of Incubation 2	5	8	12	15	18	20
7	T*	4.0	8.8	10.7	12.1	12.7	13.0	13.5
	C*	2.5	5.1	6.8	7.8	8.4	8.7	9.2
	N*	1.5	3.7	3.9	4.3	4.3	4.3	4.3
8	T	3.7	9.4					
8-A	T	4.0	9.7	11.7	13.6	14.9	15.5	16.3
	C	2.8	5.2	7.2	9.0	10.3	10.7	11.1
	N	1.2	4.5	4.5	4.6	4.6	4.8	5.2
9	T	3.5	9.1					
10	T	3.3	8.9	11.2	13.7	15.0	16.0	16.8
	C	2.9	6.3	8.3	10.0	10.-	11.4	11.9
	N	0.4	2.6	2.9	3.7	4.3	4.6	4.9
10-B	T	3.2	7.9					
11	T	3.3	6.3	7.5	9.9	11.7	13.3	14.3
	C	2.5	4.6	5.8	7.1	8.0	8.5	8.7
	N	0.8	1.7	1.7	2.8	3.7	4.8	5.6
12	T	2.0	4.2					
13	T	1.4	2.8					
14	T	0.7	1.7					
15	T	0.9	1.6					
15-A	T	0.8	1.8					
16	T	1.3	2.6					
S-1	T	0.6	1.2	3.0	30.6	32.2	36.6	38.4
	C	0.6	1.2	3.0	4.2	5.8	6.0	7.2
	N	0	0	0	26.4	26.4	30.6	31.2
S-2	T	19.0	28.2	36.8	39.6	58.8	66.6	66.6
	C	13.0	22.2	26.0	27.0	28.2	28.2	28.2
	N	6.0	6.0	10.8	12.6	30.6	38.4	38.4

*T - BOD (mg/1)
*C - CBOD (mg/1)
*N - NOD (mg/1)

TABLE # 14 (con't)

Date: 8/31/77

STA #		Days of Incubation 2	5	8	12	15	18	20
S-3	T*	19.0	28.2	36.8	39.6	58.8	66.6	66.6
	C*	13.0	22.2	26.0	27.0	28.2	28.2	28.2
	N*	6.0	6.0	10.8	12.6	30.6	38.4	38.4
S-4	T	24.1	41.4	67.0	67.2	91.2	107.6	108.6
	C	22.8	39.6	46.6	48.0	49.8	49.8	49.8
	N	1.8	1.8	20.4	19.2	41.4	57.8	58.8
S-5	T	12.6	17.4	18.8	31.6	45.0	52.8	55.8
	C	10.2	15.0	15.6	15.6	15.6	15.6	--
	N	2.4	2.4	2.4	16.0	29.4	37.2	--
S-6	T	1.2	15.0	15.0	15.0	19.2	19.2	19.2
	C	0.6	14.4	14.4	14.4	14.4	14.4	--
	N	0.6	0.6	0.6	0.6	4.8	4.8	--
S-7	T	4.8	27.6	28.8	31.2	36.6	36.6	36.6
	C	3.0	4.8	6.0	7.8	9.0	9.0	9.0
	N	1.8	22.8	22.8	23.4	27.6	27.6	27.6
S-8	T	4.8	22.2	32.2	34.9	60.0	69.6	70.2
	C	4.8	9.8	11.2	13.5	14.0	14.4	14.4
	N	0	12.4	21.0	21.4	46.0	55.2	55.8

Date: 9/08/77

STA #		3	5	7	10	15	17	20
P-8	T	1.4	2.0	3.0	4.0	5.3	6.4	6.5
	C	1.4	2.0	2.6	3.3	3.7	4.4	4.5
	N	0	0	0.4	0.7	1.6	2.0	2.0
P-4	T	2.0	2.6					
1	T	2.2	2.7	3.5	5.0	5.8	6.5	6.7
	C	2.0	2.6	3.3	3.6	4.2	4.4	4.5
	N	0.2	0.1	0.2	1.4	1.6	2.1	2.2
1-A	T	1.2	1.8					
2	T	1.6	2.4					
3	T	3.9	5.3	7.0	8.0	8.7	9.1	9.5
	C	1.8	2.5	3.2	3.7	4.2	4.6	5.0
	N	2.1	2.8	3.8	4.3	4.5	4.5	4.5

*T - BOD (mg/1)
*C - CBOD (mg/1)
*N - NOD (mg/1)

TABLE # 14 (con't)

Date: 9/08/77

STA #		Days of Incubation 3	5	7	10	15	17	20
4	T*	5.5	9.4	13.5	14.6	15.4	16.1	16.3
	C*	3.7	4.8	5.8	6.2	6.8	7.1	7.4
	N*	1.8	4.6	7.7	8.4	8.6	9.0	8.9
5	T	6.5	11.8	16.5	17.8	19.0	19.6	19.8
	C	3.1	4.8	5.9	6.8	8.0	8.4	8.8
	N	3.4	7.0	10.6	11.0	11.0	11.0	11.0
5-A	T	7.0	11.2					
6	T	4.9	6.6	8.2	9.4	10.3	11.4	11.6
7	T	3.8	4.6	5.5	6.2	7.0	7.9	8.1
	C	1.9	2.6	3.4	3.8	3.8	4.3	4.5
	N	1.9	2.0	2.1	2.4	3.2	3.6	3.6
8	T	3.5	4.7					
8-A	T	3.6	5.0	6.2	6.9	8.0	8.8	9.1
	C	2.5	3.2	4.3	4.6	4.9	5.7	6.1
	N	1.1	1.8	1.9	2.3	3.1	3.1	3.0
9	T	3.1	4.6					
10	T	1.8	4.9	5.8	7.2	8.6	9.6	9.8
	C	1.0	2.9	4.8	6.0	6.7	7.2	7.3
	N	0.8	1.0	1.0	1.2	1.9	2.4	2.5
10-B	T	3.2	4.9					
11	T	2.3	3.6	4.7	7.2	8.8	9.6	9.9
	C	1.8	3.1	3.6	4.8	5.8	6.6	6.9
	N	0.5	0.5	1.1	2.4	3.0	3.0	3.0
12	T	2.2	3.1					
13	T	2.6	3.4					
14	T	1.3	1.6					
15	T	1.2	1.8					
15-A	T	0.6	1.2					

*T - BOD (mg/1)
*C - CBOD (mg/1)
*N - NOD (mg/1)

TABLE # 14 (con't)

Date: 9/08/77

STA #		Days of Incubation 3	5	7	10	15	17	20
16	T	1.3	1.7					
S-1	T*	1.0	11.7	17.1	26.6	26.6	53.4	54.0
	C*	1.0	5.4	6.0	9.9	9.9	11.1	12.0
	N*	0	6.3	11.1	16.7	16.7	42.3	42.0
S-2	T	9.6	15.6	15.6	41.4	69.0	72.0	72.6
	C	5.4	5.4	5.4	6.0	--	--	--
	N	4.2	10.2	10.2	35.4	--	--	--
S-3	T	102.0	132.0	132.0	183.0	220.0	264.	270.
	C	102.0	90.0	90.0	111.0	--	--	--
	N	0	42.0	42.0	72.0	--	--	--
S-4	T	31.0	69.0	79.6	98.6	131.0	171.6	172.2
	C	31.0	57.6	67.2	76.4	80.0	83.3	84.6
	N	0	11.4	12.4	22.2	51.0	88.3	87.6
S-5	T	8.2	19.2	22.2	25.2	33.6	63.6	66.6
	C	8.2	12.0	15.0	18.0	22.2	23.4	25.4
	N	0	7.2	7.2	7.2	11.4	40.4	41.2
S-6	T	7.0	16.8	24.0	43.2	47.8	55.8	55.8
	C	7.0	12.0	15.0	17.4	21.4	21.4	21.0
	N	0	4.8	9.0	25.8	26.4	34.3	34.8
S-7	T	5.1	14.7	16.2	37.8	51.0	59.4	62.4
	C	4.5	8.4	8.4	8.4	12.6	16.2	18.0
	N	0.6	6.3	7.8	29.4	38.4	43.2	44.0
S-8	T	4.2	15.6	17.4	40.2	65.4	101.4	104.4
	C	4.2	9.0	9.6	13.2	18.7	22.8	27.9
	N	0.0	6.6	7.8	27.0	46.7	78.6	76.5

*T - BOD (mg/1)
*C - CBOD (mg/1)
*N - NOD 9mg/1)

TECHNICAL REPORT DATA (Please read Instructions on the reverse before completing)		
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15. SUPPLEMENTARY NOTES		

16. ABSTRACT

The biochemical oxygen demand of Potomac River and STP effluent samples was determined during the summer of 1977. The fraction associated with N.O.D. was measured using an inhibitor to nitrification and the oxygen depletion was monitored during long term incubation. The average deoxygenation constants for the river sample C.B.O.D. and N.O.D. were 0.14 day^{-1} (k_e). The N.O.D. was found to be a significant component of the $B.O.D._5$ for STP effluent and river samples. The peak C.B.O.D. was associated with an algal bloom of <u>Oscillatoria.</u>

17. KEY WORDS AND DOCUMENT ANALYSIS		
a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
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